PART 4

WAISOI MINERALISATION AND ALTERATION

4.1 PROSPECT MINERALISATION

4.1.1 General

Throughout the Namosi district, porphyry-style copper +/- gold +/- molybdenum is the dominant style of mineralisation, with some re-mobilised vein-style copper/gold mineralisation and only minor epithermal-style gold and distal vein-style base metal mineralisation. The main areas of porphyry mineralisation in the district (Figure 4.1) are at:

- Waisoi - in three large tonnage, low-grade copper deposits known as:
  - Waisoi West, the largest of the Waisoi deposits and the site of the original discovery outcrop,
  - Waisoi East, geologically the simplest of the Waisoi deposits and containing most of the known molybdenum, and
  - Waisoi North, the most recently discovered (1992) of the Waisoi deposits;
- Wainabama - where re-mobilised high-grade copper/gold porphyry-style mineralisation is on the margin of an inferred, larger, lower-grade porphyry-style system, and
- Waivaka - where structurally concentrated high-grade copper/gold mineralisation occurs in a large area of low-grade porphyry-style copper mineralisation.

Other styles of mineralisation in the area (Figure 4.2) include:

- some minor distal vein-style gold mineralisation, which occur:
  - to the southeast of the Waisoi deposits at Wainisavusavu/Wainabavatu
  - to the northeast of the Waisoi deposits at Waininui, Wainimoli and Wainavadu
  - to the north of the Waisoi deposits at Wainavandu.
- distal base metal vein-style mineralisation which occurs between the Waisoi and Wainabama porphyry deposits along a major structure

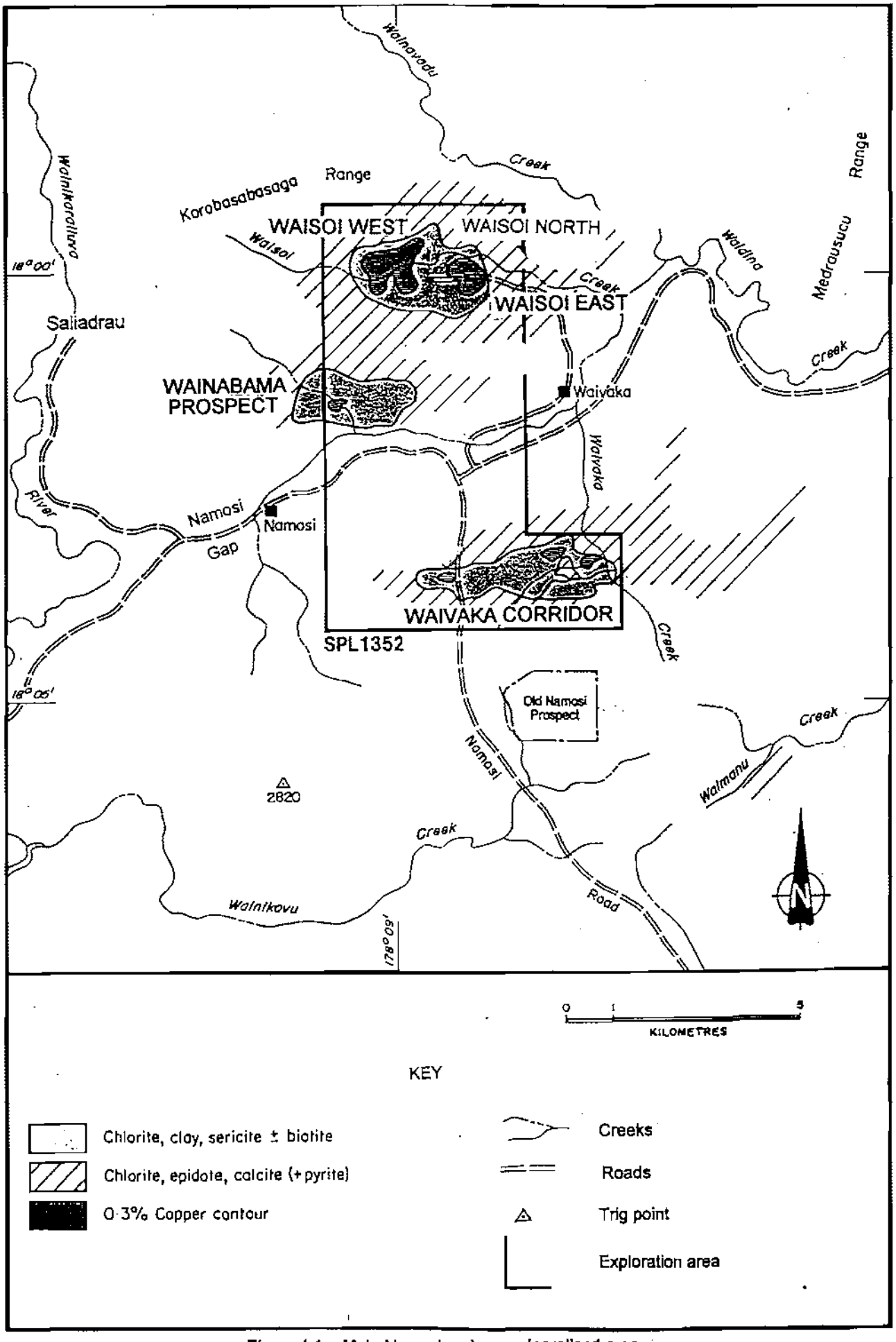


Figure 4.1 Main Namosi porhryry mineralised areas.

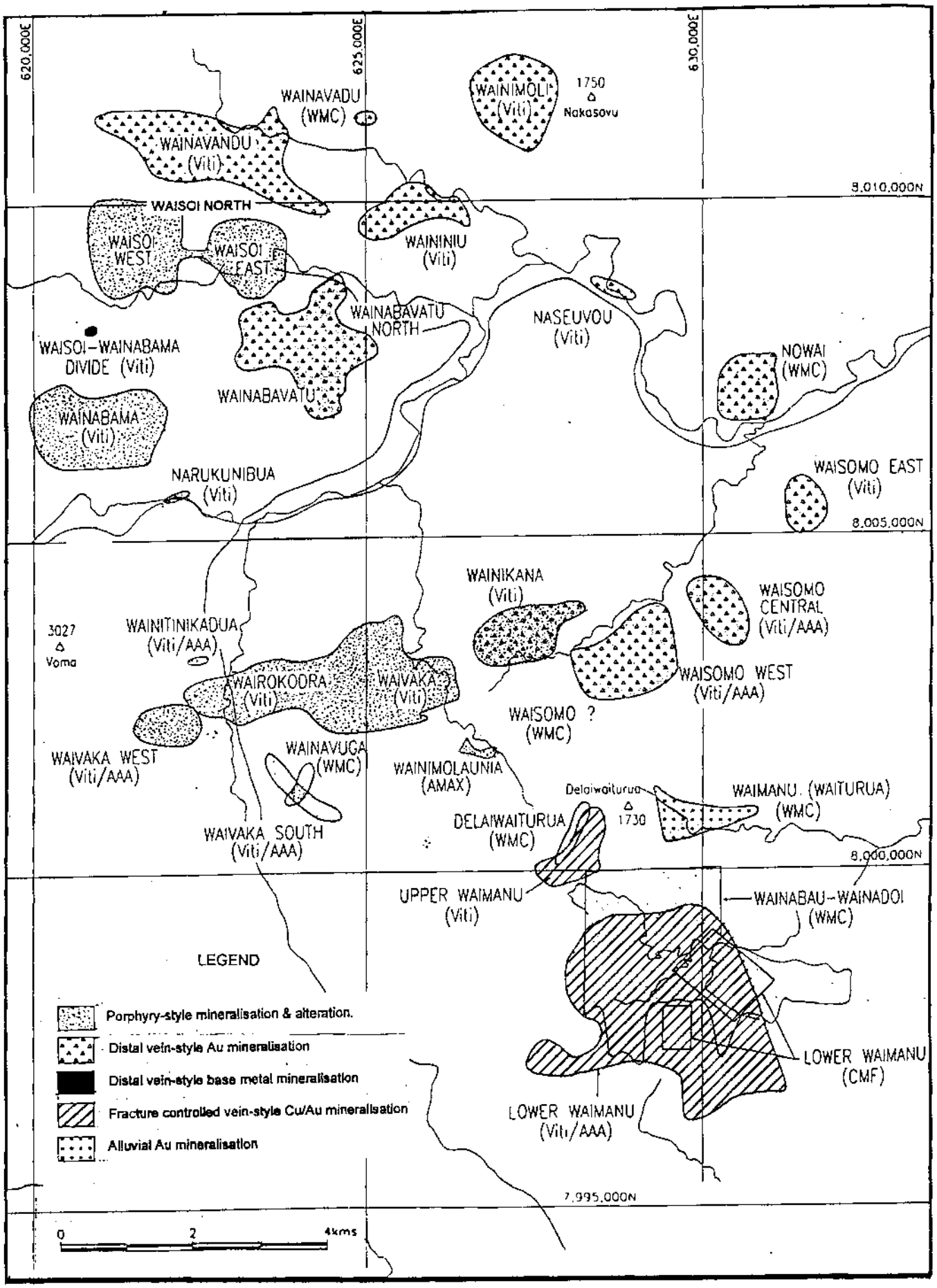


Figure 4.2 Mineralised prospects in the Namosi area.

- Copper-gold mineralisation in the Wainabau/Waimanu area appears to be fault/fracture-controlled.
- other minor, non-economic, mostly gold accumulations in hard-rock and alluvial type environments.

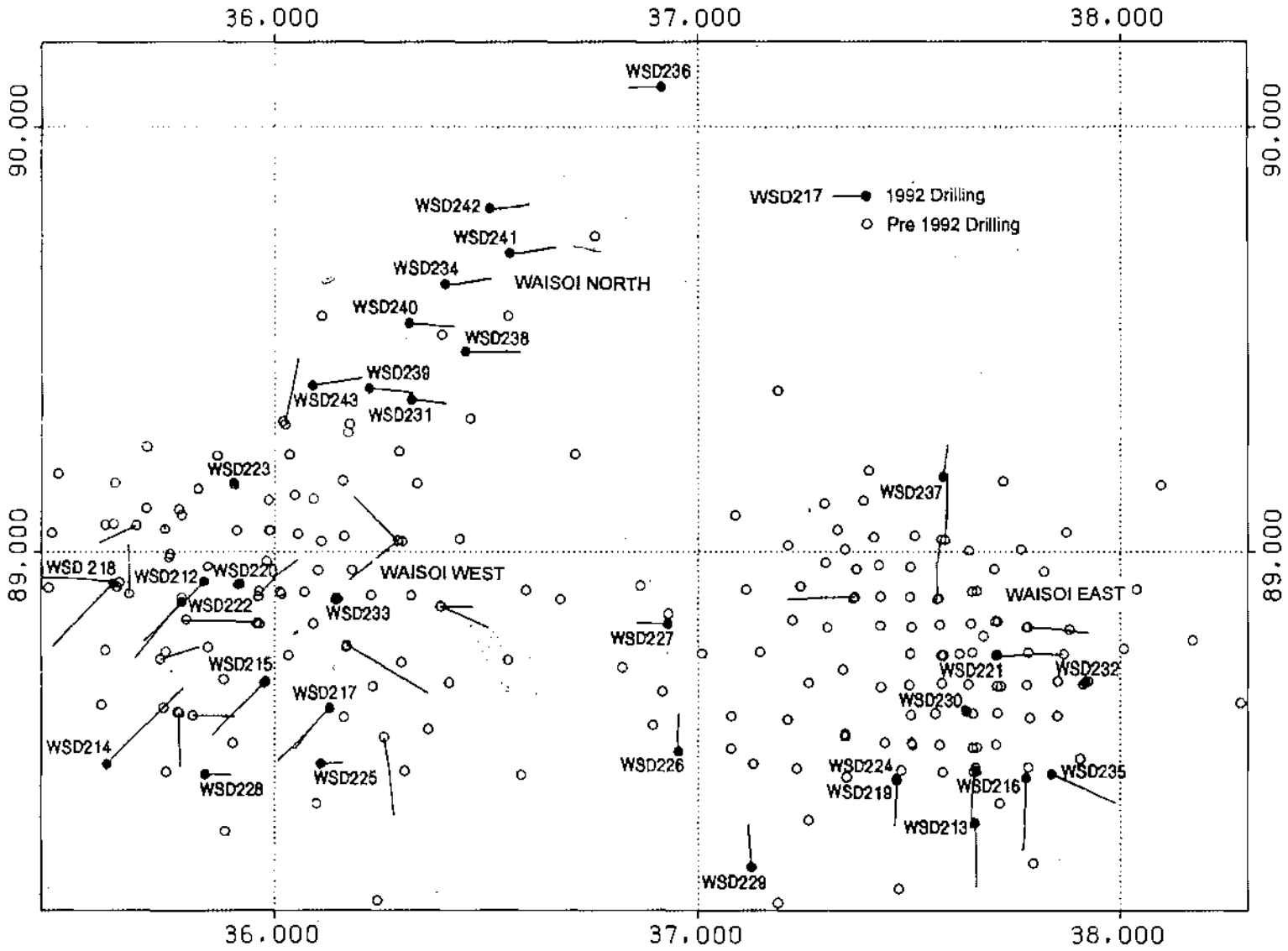
The only mineralisation to be examined in more detail will be that occurring within the Waisoi porphyry copper +/- gold deposits.

4.1.2 Waisoi Mineralisation

Although the Waisoi mineralisation outcrops, and was discovered by a combination of drainage geochemistry and associated follow-up geological mapping, most of the detailed information about the mineralisation has been determined from the core from 243 drill holes. Overall distributions and styles of mineralisation have been determined mainly from careful drill core logging and analysis, with details of the mineral species and their relationships determined by thin section examinations. The relationship of the mineralisation to the alteration was also determined from thin section evaluation.

The main Waisoi porphyry-style mineralisation is associated with the P1 and P4 contemporaneous intrusions (see Chapter 3.1.2.5). These porphyries have both disseminated and micro-veinlet styles of mineralisation concentrated in the cupola region and surrounding brecciated halos. Most of the mineralisation in the Waisoi district is associated with some degree of quartz veining (generally 1 to 10% quartz veins in the rock), with higher copper values being in strongly fractured zones. In general, the Waisoi porphyry mineralisation tends to be low in sulphur (W. Lacy, pers.comm., 1992), with an average of only 0.5 - 5.0% sulphides (locally to 10%) compared to 5 - 15% sulphides in many porphyry systems in the SW Pacific region (Sillitoe, 1989).

The drilling to date (Figure 4.3) has defined the eastern and southern limits to Waisoi East mineralisation. Further drilling to the north-northwest, southwest and west of Waisoi East may close the mineralised annulus around the uplifted western P4 porphyry block. Waisoi West mineralisation is still open to the south, southwest, west, and at depth to the north and northwest. Further drilling in the



NAMOSI PROSPECT – FIJI

Waisoi Drill Hole Locations

Figure 4.3

area to the east and southeast of Waisoi North and east and northeast of Waisoi West on the structural trends may define further mineralisation. These limits to the mineralisation has been confirmed by an IP survey interpretation (Figure 4.4). The distribution of pyrite and chalcopyrite, even though their concentrations are generally low, is such that IP is an effective means of defining the limits of the Waisoi porphyry system.

4.1.2.1 General Distribution

Adjacent to the porphyries, the copper mineralisation (species identified using the data of Spry and Gedlinski, 1987; Groves, 1991) is dominantly bornite, covellite and digenite (after covellite) as both disseminated and fracture/joint-coating mineralisation. Away from the porphyry margins, bornite/digenite/covellite decreases as chalcopyrite increases (until only chalcopyrite occurs). Further out from the porphyry margins the chalcopyrite decreases (to an elevated background of around 0.1-0.3% chalcopyrite) with no corresponding change in pyrite content. Outwards the chalcopyrite continues to decrease slowly (as it is replaced by pyrite) to a distance of around 1000m from the intrusives, where the copper values are in the order of 100-200ppm. Pyrite is constant but low throughout the deposits, averaging around 5% by volume. However, outward from the intrusives for at least 1000m, pyrite increases through a series of zones, but is inversely related to chalcopyrite in the outer zone. This relationship gives a characteristic annular IP and magnetic anomaly. Beyond about 1000m from the intrusives, the amount of primary magnetite replaced by pyrite decreases to a distance in excess of 4 km.

Pyrite also increases markedly in clay/quartz zones of faults which are almost copper-free.

Within the porphyries in Waisoi East, the copper mineralisation distribution may be explained by the presence of a north-south late stage block fault. To the east of this fault (around 37505mE), in the downthrown side, Cu/Au mineralisation occurs within and around the top of the porphyry (in Wainimala Agglomerate). West of the fault the porphyry has been uplifted and the mineralisation in and around the top of the porphyry has been eroded. Now the

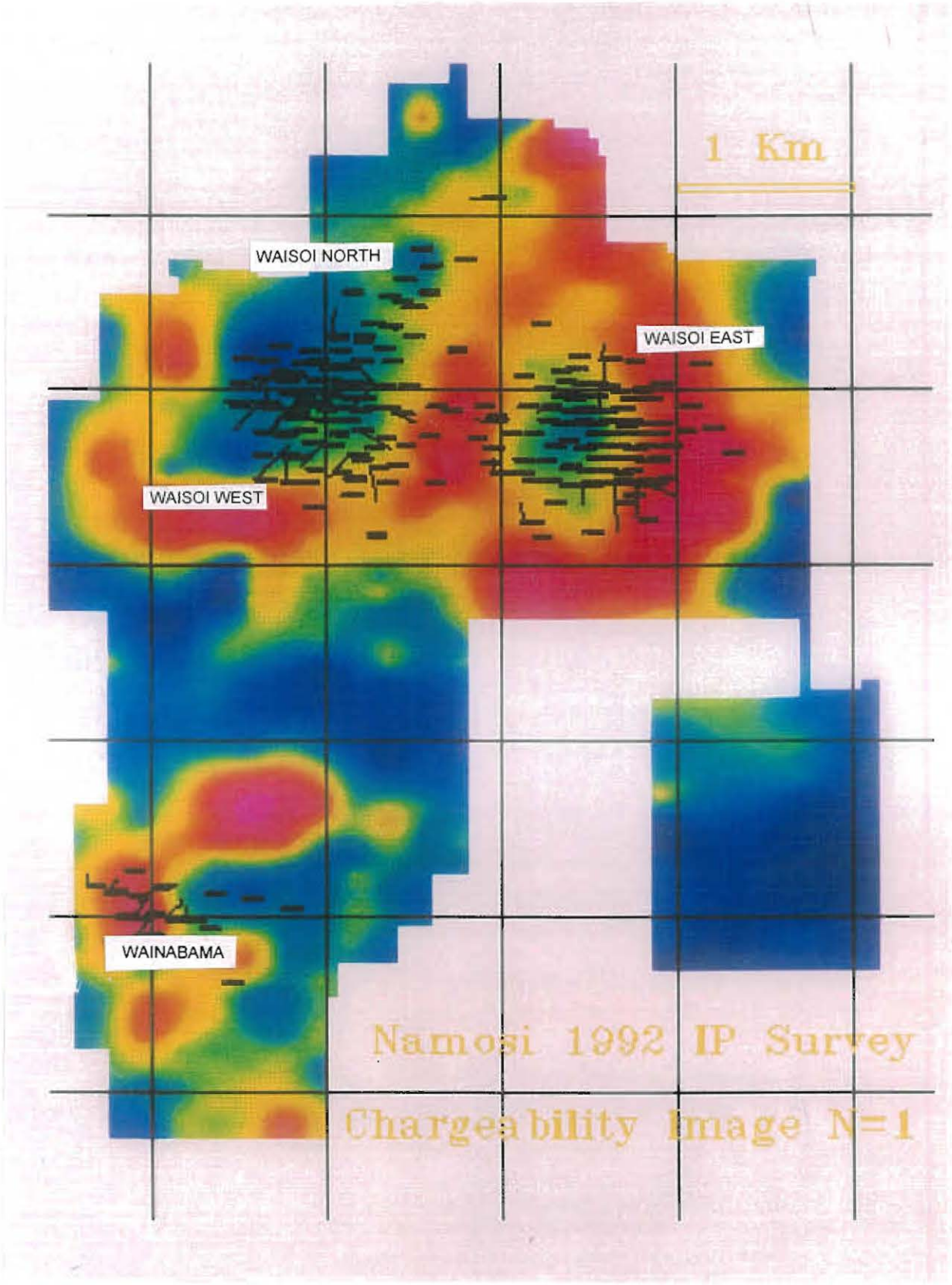


Plate 4.4 Image of an IP survey showing the chargeability anomalies over the porphyry mineralisation.

only remaining mineralisation west of the fault is the mineralisation in and around the edges of the intruding porphyry. The centre of the exposed porphyry is the unmineralised and/or siliceous core. Other north-south (west side up) block faults may occur to the west of Waisoi East and may explain the presence of the relatively unmineralised (but poorly understood) P4 type porphyries in this area (i.e. the core barren part of a large P4 porphyry).

Magnetite variations are not fully understood but increased concentrations of magnetite occur in zones of intense chalcopyrite/bornite mineralisation. This has led to the zones adjacent to the intrusions having an increased magnetite content, and therefore a significant magnetic anomaly. This association of magnetite concentration in areas of high-grade bornite mineralisation may be a useful way of exploring for high-grade zones by detailed magnetic surveying across the porphyry deposits.

From observations made in drill core samples, the dominant style of mineralisation occurring in the Wainimala Agglomerate is vein related. The lavas were brecciated and shattered prior to the introduction of the mineralising fluids. The sulphide mineralisation occurs in veinlets that vary from around 40 microns (micro-veinlets) up to a few centimetres across (most common vein width is 0.2 - 0.5mm), and vary in density from 5 - 10 per metre up to 100's per metre. The sulphides often occur as anhedral grains, up to 1 millimetre, in sugary-textured, quartz-rich veins. Less common are complexly zoned veins where sulphide mineralisation appears to be unrelated to the primary porphyry-related, mineralising episodes.

This remobilised sulphide mineralisation consists of veinlets (up to a few centimetres across) of mainly coarse (up to 1cm), anhedral to subhedral grains of pyrite and chalcopyrite, with some bornite in crystalline quartz and/or quartz-carbonate. These occur mainly in the Basal Namosi Conglomerate (as irregular infill in a porous and permeable unit), with some in the Wainimala Agglomerate and minor occurrences in the Namosi Andesite, adjacent to major structures. The re-mobilised sulphides are more coarse and less variable (almost

exclusively intergrown pyrite and chalcopyrite, with minor bornite) than the sulphides in the primary mineralisation.

The Namosi Andesite is dominated by fine-grained, disseminated sulphide mineralisation, characterised mainly by chalcopyrite and pyrite. This is dominantly as tiny, anhedral grains throughout the volcanics.

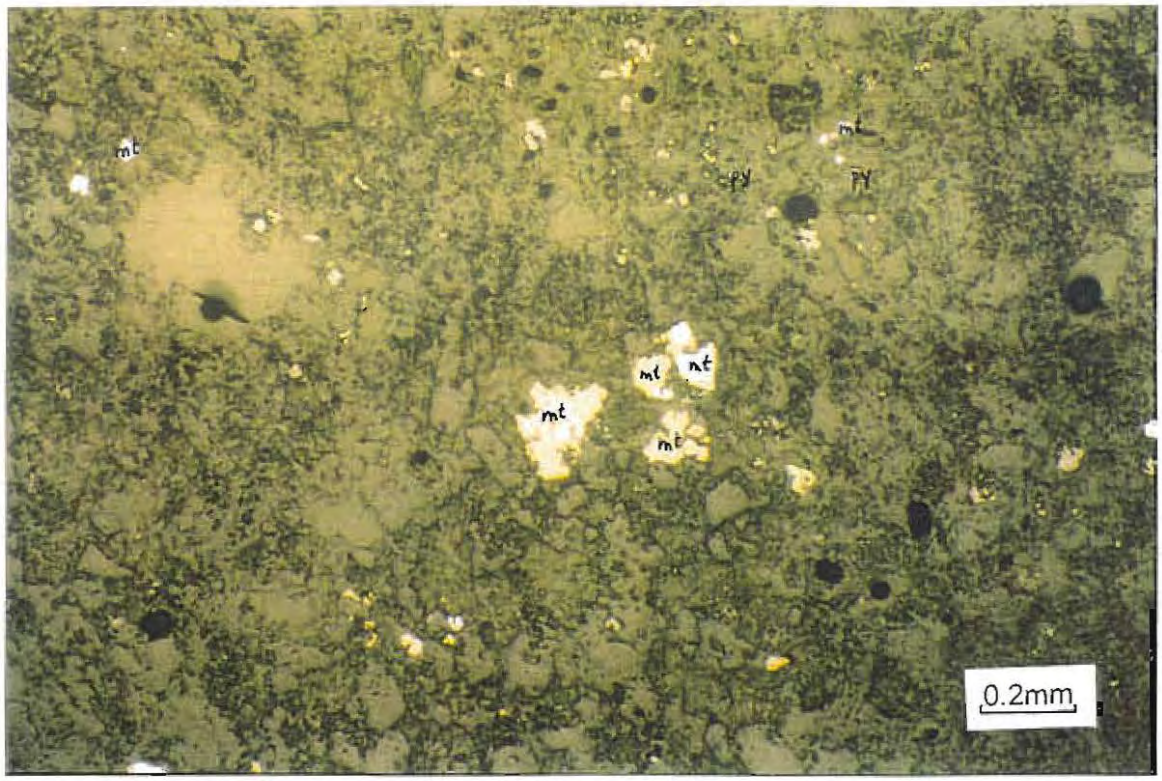
Apart from the lithological and deposit scale relationships, determined from outcrop mapping, drill core logging and drill sample assays, small scale relationships of mineralisation and alteration within the Waisoi porphyry system were determined by the examination of 196 thin section samples. Most of these samples were collected from drill core from the 1992 drilling programme of Waisoi West, Waisoi North and Waisoi East (Figure 4.3), with a few samples being from the earlier AMAX drilling. The study of the thin sections showed that the copper mineralisation occurred mainly as fine-grained disseminations throughout the host volcanics, and in thin, quartz-rich, micro-veinlets to veins. Minor amounts of copper occurred in massive sulphide pods. There are rare zones of secondary copper enrichment.

4.1.2.2 Disseminated Mineralisation

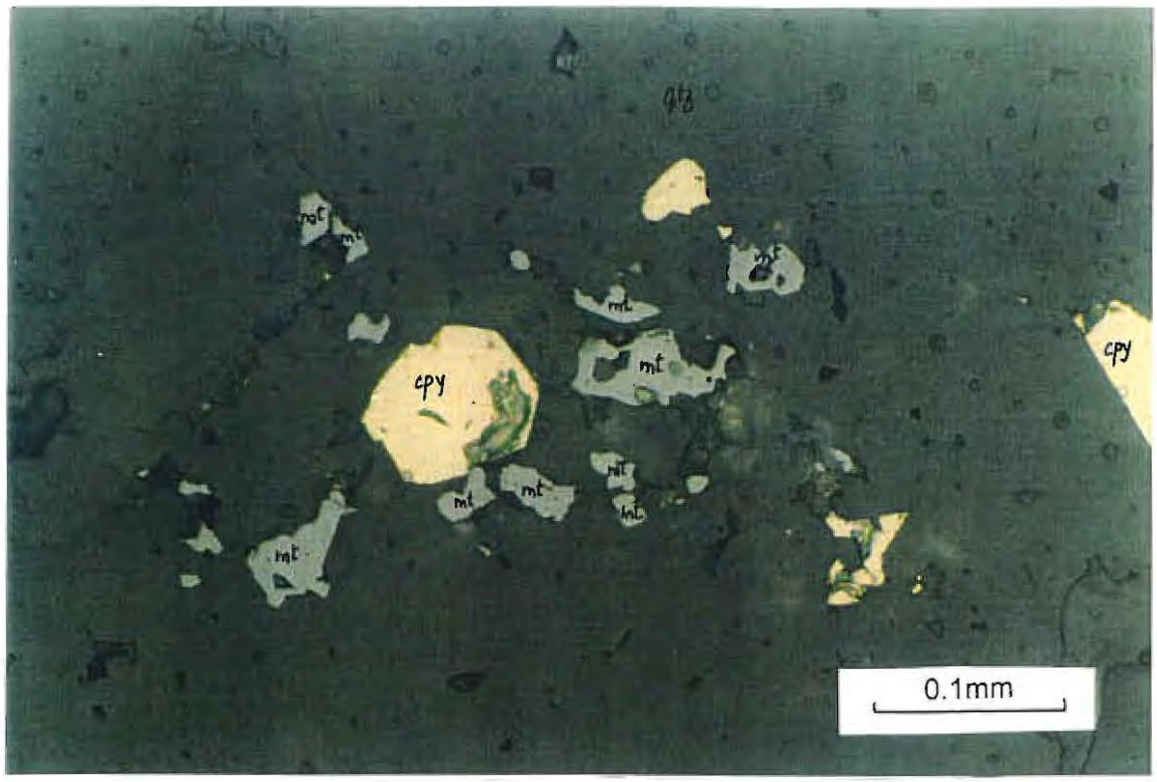
A large proportion of the Waisoi porphyry copper mineralisation occurs as zones (or domains) of dominantly fine-grained (as less than 10 microns), disseminated, anhedral sulphide grains (Plate 4.1). These domains, which have diameters varying from sub-centimetre to tens-of-metres, are randomly distributed throughout the Waisoi deposits, but are more prominent in the lavas and volcaniclastics of the Namosi Andesite.

Almost all of the mineralisation occurring in the Namosi Andesite consists of fine-grained, anhedral, disseminated chalcopyrite +/- pyrite. The chalcopyrite has usually replaced pyrite (Plate 4.2), which had previously replaced primary magnetite. The chalcopyrite, in turn, has been partially replaced by a late stage pyrite.

The sulphide mineralisation occurring in the Basal Namosi Conglomerate and the Wainimala Agglomerate consisted of both disseminated and vein/space-fill

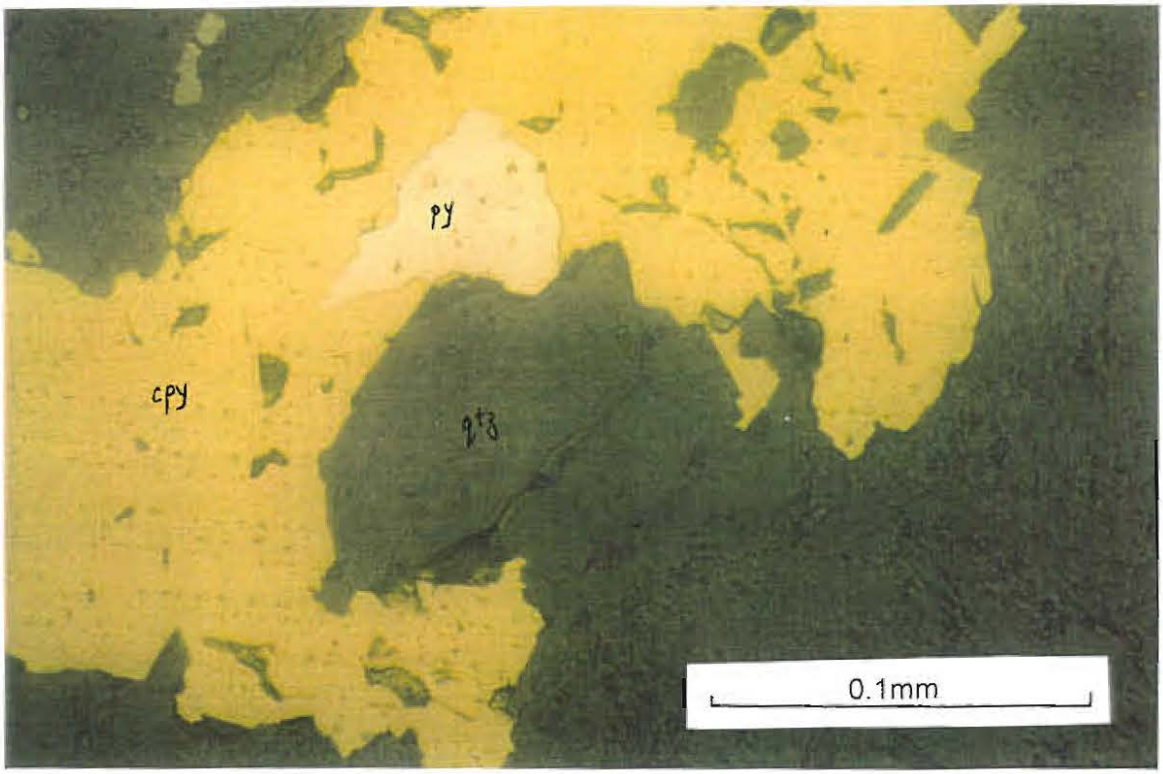


(a) Fine-grained pyrite euhedra and irregular magnetite grains in the Namosi Andesite (reflected light). WSD 234 - 110.90m

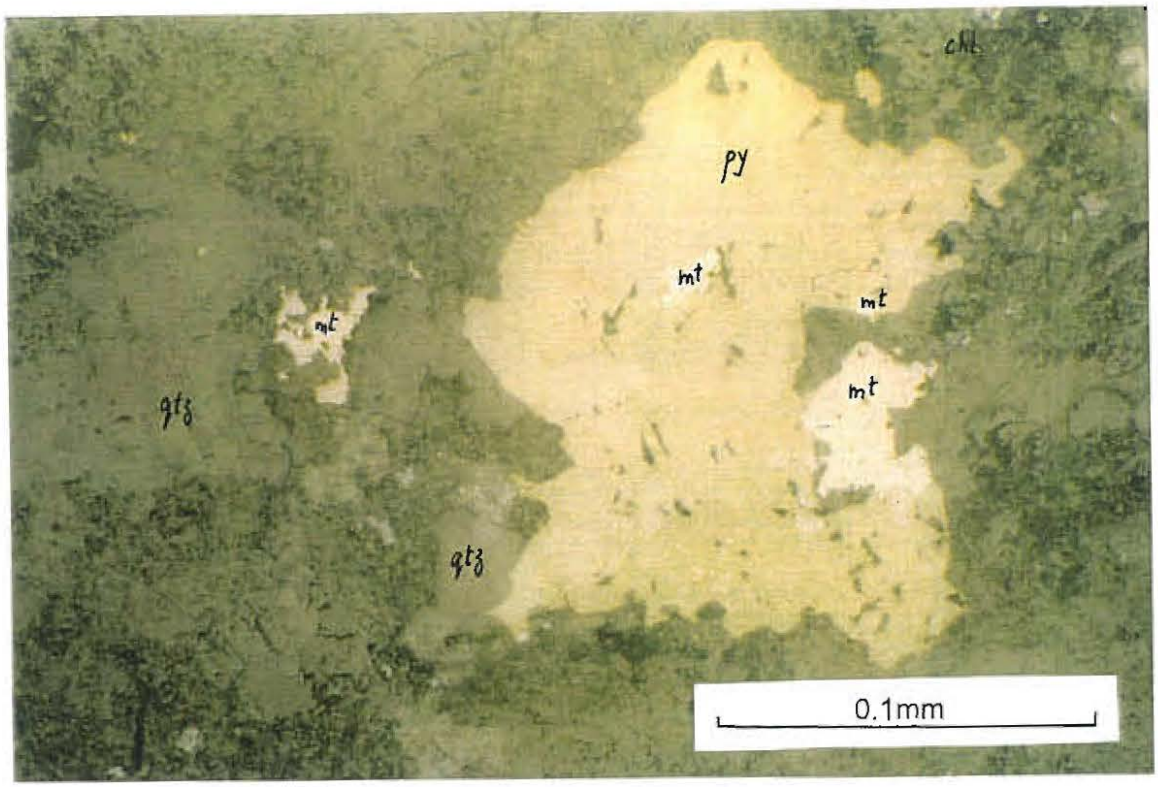


(b) Concentration of magnetite grains with chalcopyrite (reflected light). WSD 228 - 320.75m

Plate 4.1 Examples of disseminated sulphide mineralisation.



(a) Chalcopyrite replacing pyrite (reflected light). WSD 228 - 117.40m



(b) Pyrite replacing magnetite (reflected light). WSD 234 - 110.90m

Plate 4.2 Disseminated chalcopyrite, pyrite and magnetite.

types. The disseminated mineralisation is again dominantly chalcopyrite +/- pyrite, but with some bornite in areas adjacent to the intrusions and in the vicinity of significant fluid channel-ways (around pebbles) and/or veins (fractures through pebbles). The bornite replaces chalcopyrite and pyrite and is replaced by later chalcopyrite and/or pyrite (Plate 4.3). Minor covellite and digenite also occur in the vicinity of intrusions. The digenite replaces and pseudomorphs the covellite blades.

4.1.2.3 Vein Mineralisation

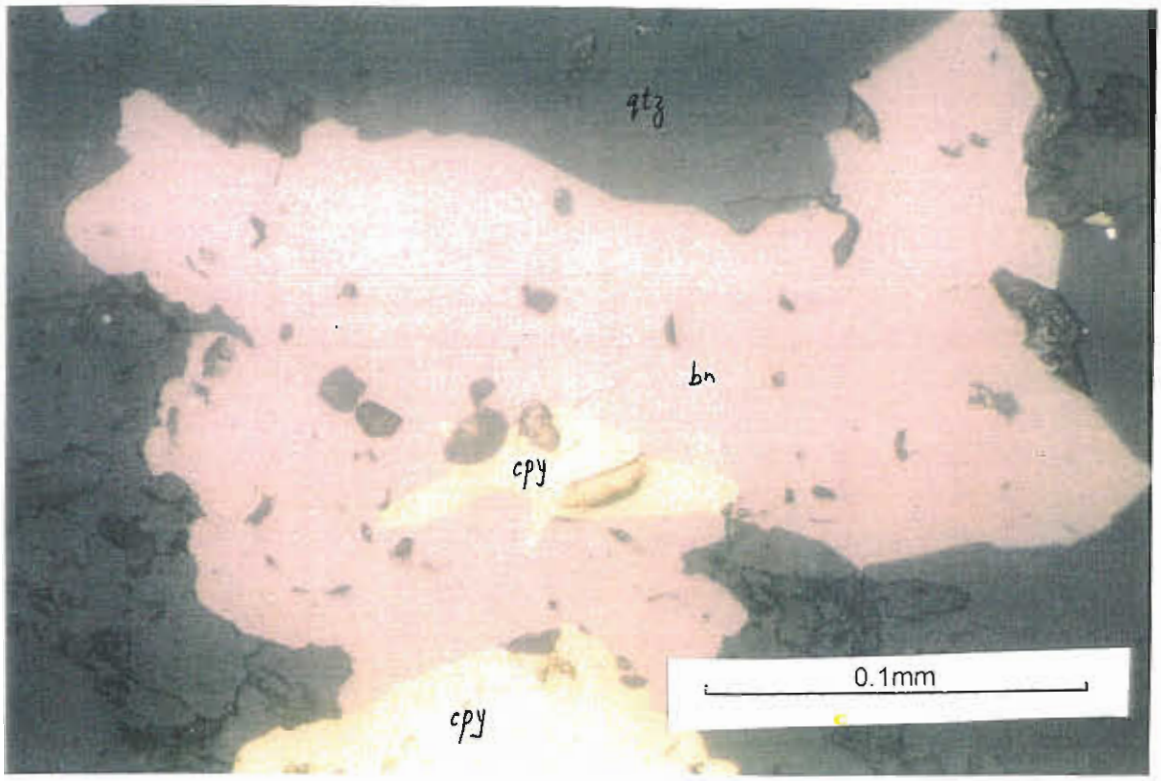
At Waisoi there is a significant amount of chalcopyrite +/- bornite +/- digenite, with quartz, in a stockwork of micro-veinlets to thin veins (Plate 4.4). These veins are concentrated in areas of higher-grade copper/gold mineralisation within the Wainimala Agglomerate and the Basal Namosi Conglomerate. The veins/veinlets are the result of both primary porphyry-related mineralisation (directly associated with the intrusion of the porphyries) and re-mobilised porphyry mineralisation.

The primary porphyry-related sulphide mineralisation is basically a stockwork of micro-veinlets composed of chalcopyrite with varying amounts of bornite, and minor digenite, chalcocite and covellite (Plate 4.5). The digenite and chalcocite replace the covellite. Some pyrite is also present. The stockwork is not uniform throughout the deposits, but are more prevalent in particular zones related to brecciation along structures and/or fluid channel-ways projecting out from the intrusives.

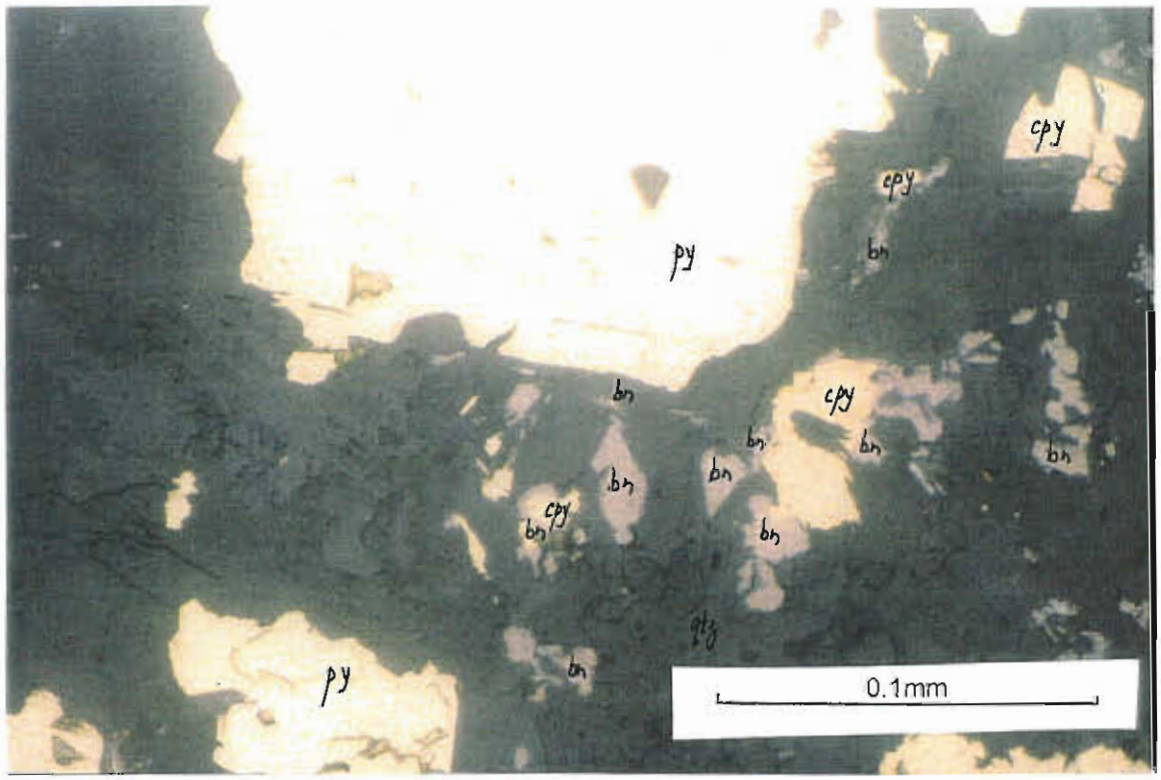
The chalcopyrite occurs as anhedral to subhedral grains in a sugary-textured poly-crystalline quartz vein, sometimes with associated pyrite (Plate 4.6). Commonly the chalcopyrite grains show corroded margins and are often being replaced by other sulphides, particularly pyrite and, less commonly, by bornite.

Bornite occurs as:

- tiny, individual, anhedral grains in the poly-crystalline quartz veins associated with chalcopyrite +/- pyrite,
- fine-grained, irregular intergrowths with chalcopyrite,
- fine-grained, overgrowths with replacement textures over chalcopyrite,

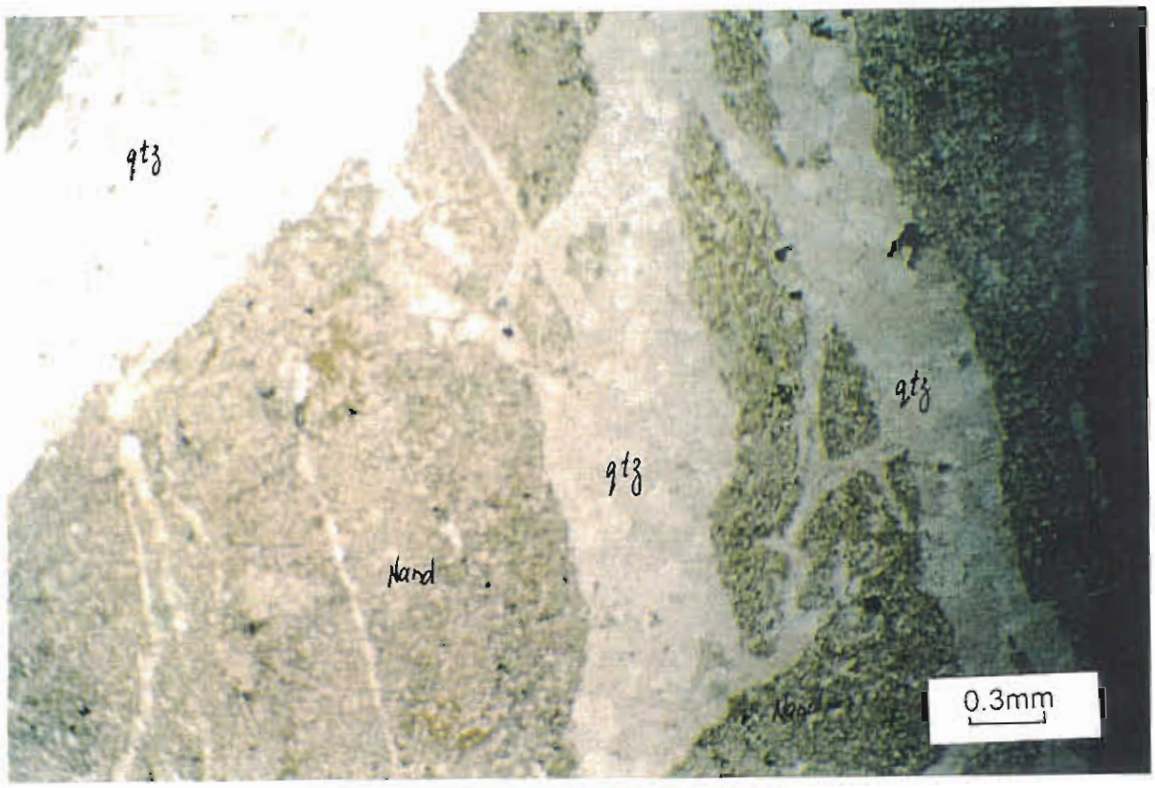


(a) Bornite replacing chalcopyrite (reflected light). WSD 238 - 137.80m

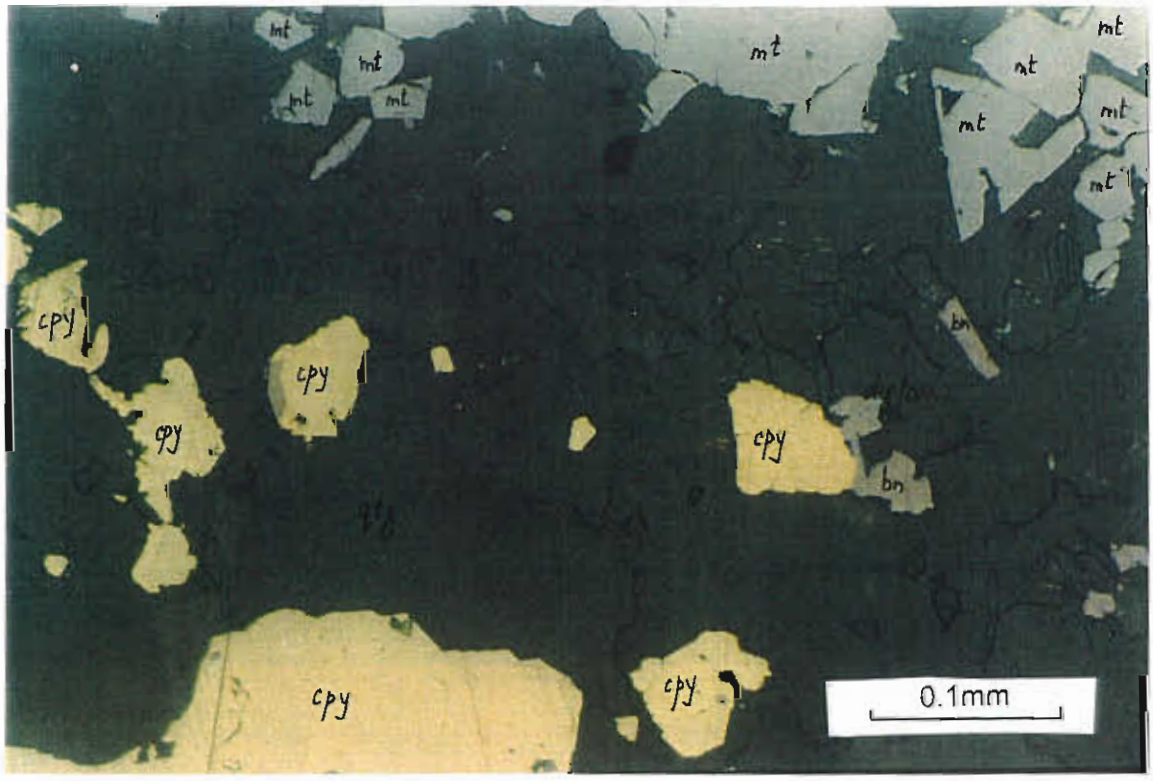


(b) Bornite replacing pyrite and chalcopyrite (reflected light)
WSD 234 - 110.90m.

Plate 4.3 Disseminated chalcopyrite, bornite and pyrite.

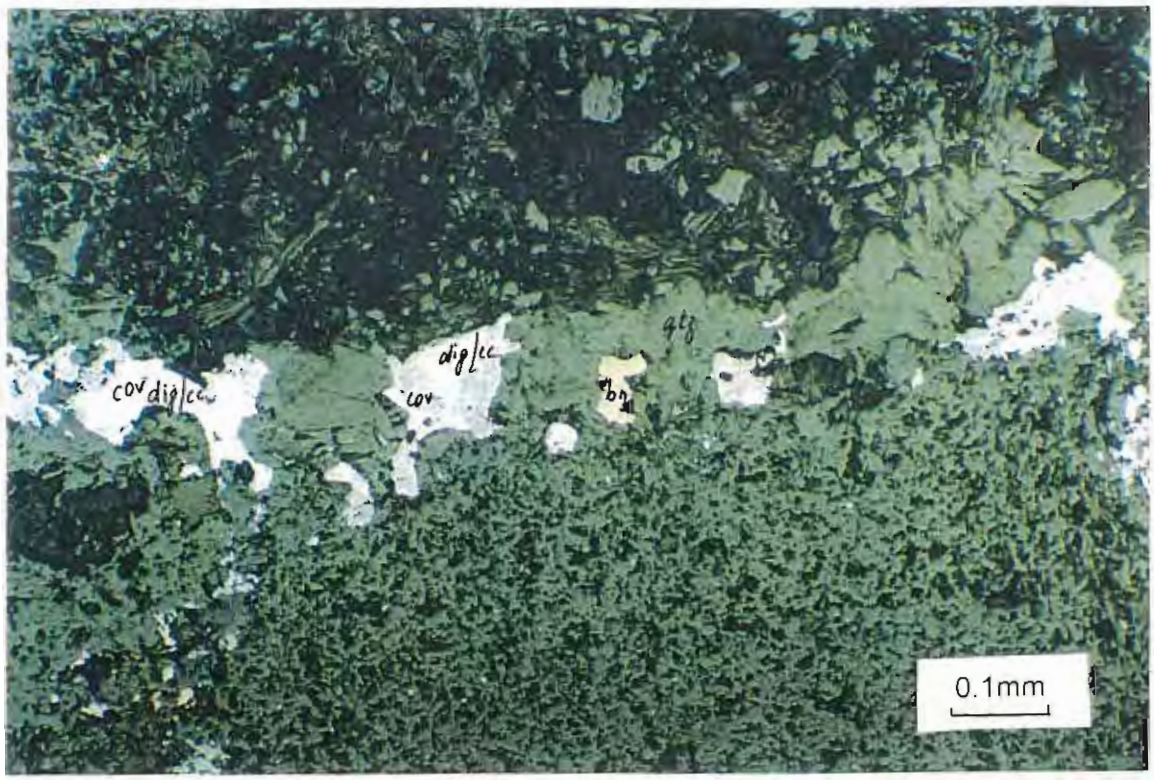


(a) Polycrystalline quartz with minor sulphides (plain light) forming a stockwork in Namosi Andesite WSD 217 - 95.00m

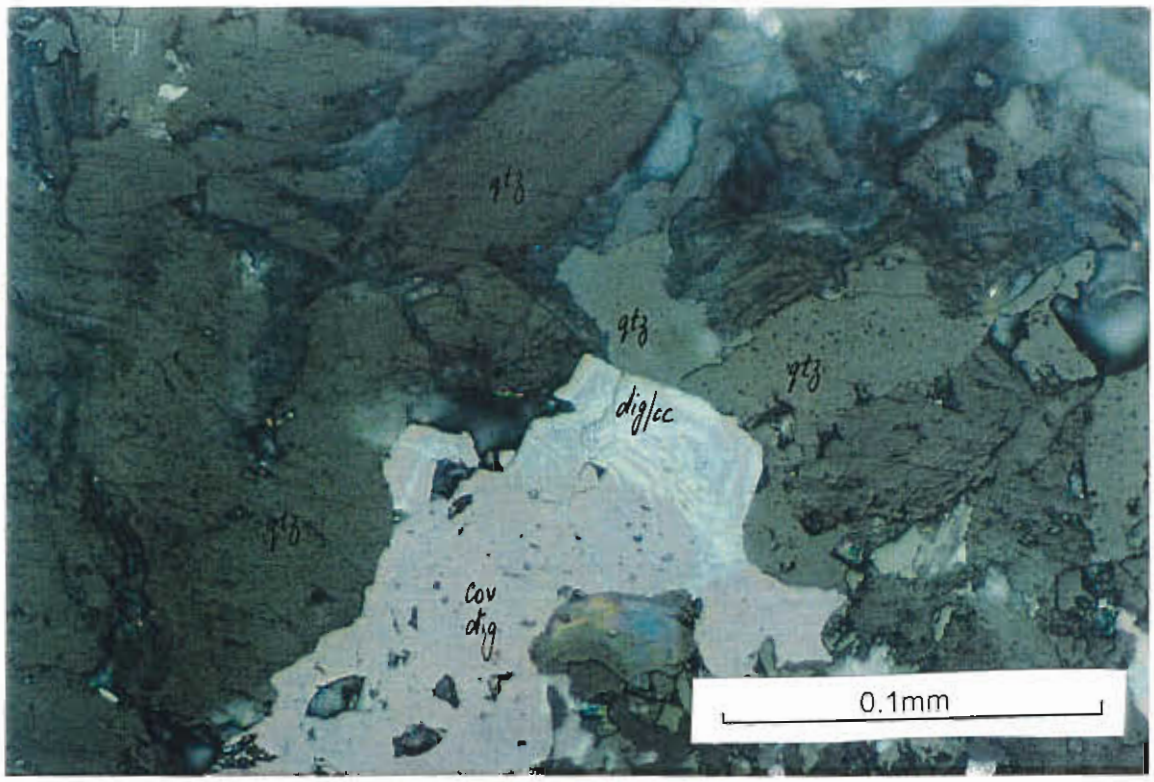


(b) Chalcopyrite and bornite in quartz within a stockwork zone (reflected light). WSD 234 - 106.35m

Plate 4.4 Quartz stockwork vein mineralisation.

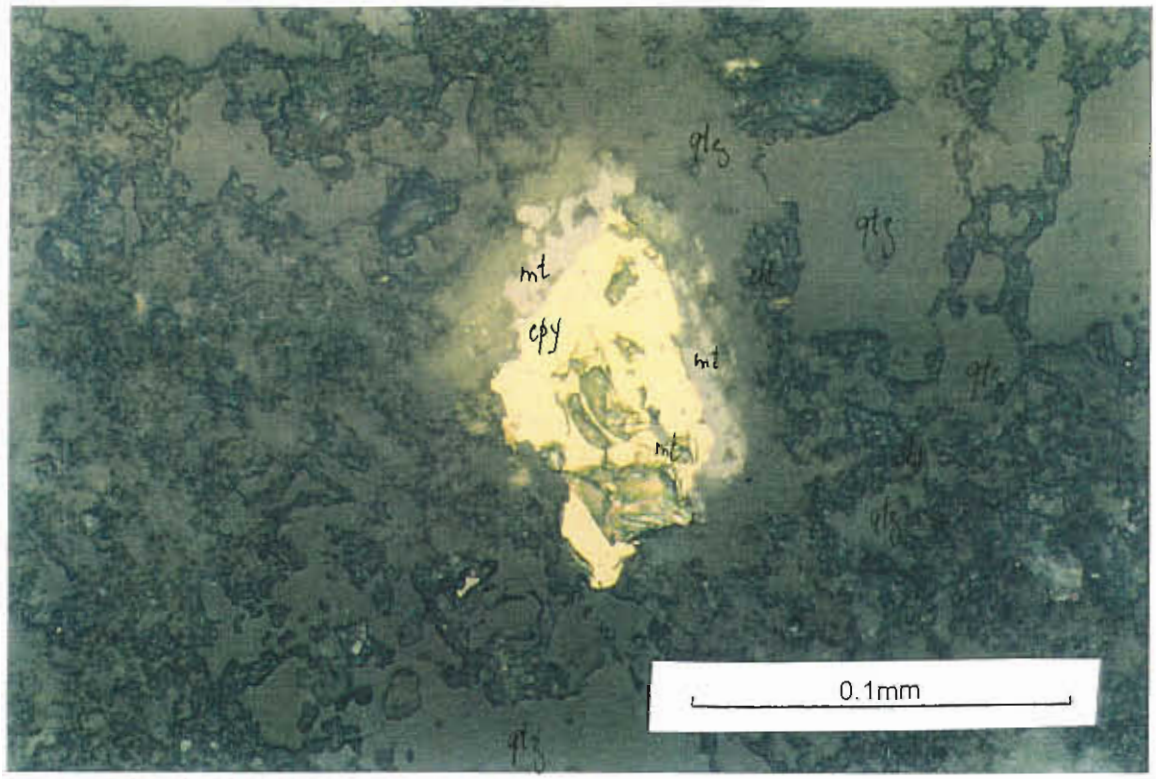


(a) Bornite, covellite, digenite and chalcocite in quartz (reflected light). within chlorite altered Wainimala Agglomerate lavas WSD 212 - 235.00m



(b) A grain of covellite, digenite and chalcocite in quartz (reflected light). WSD 212 - 235.00m

Plate 4.5 Quartz micro-veinlets hosting copper mineralisation.



(a) Chalcopyrite replacing magnetite (reflected light). WSD 228 - 117.40m

(b) Pyrite euhedral with irregular chalcopyrite (reflected light). WSD 212 - 67.80m

Plate 4.6 Sulphide grains in polycrystalline quartz.

- tiny, anhedral grains being replaced by chalcopyrite, or
- small, anhedral grains being replaced and overgrown by pyrite.

The digenite, chalcocite and covellite occur only intimately associated with the bornite, characteristically showing exsolution textures. The digenite and covellite are both extremely fine-grained (commonly >20 micron), and only occur in the vicinity of the contacts of the porphyries, particularly in the Waisoi North - Waisoi West area. Both digenite and chalcocite are intimately associated with covellite blades.

Although of no economic significance, pyrite is commonly associated with copper sulphide species (particularly chalcopyrite) throughout the deposit. Fine- to coarse-grained, anhedral pyrite occurs in most of the quartz veinlets (Plate 4.7), whether they are the very early or very late stages of the emplacement of the porphyry mineralisation. As such, the pyrite shows features similar to the chalcopyrite, with the pyrite being:

- replaced by chalcopyrite, bornite and covellite,
- intergrown with chalcopyrite and bornite,
- being corroded by chalcopyrite and, rarely, by bornite.

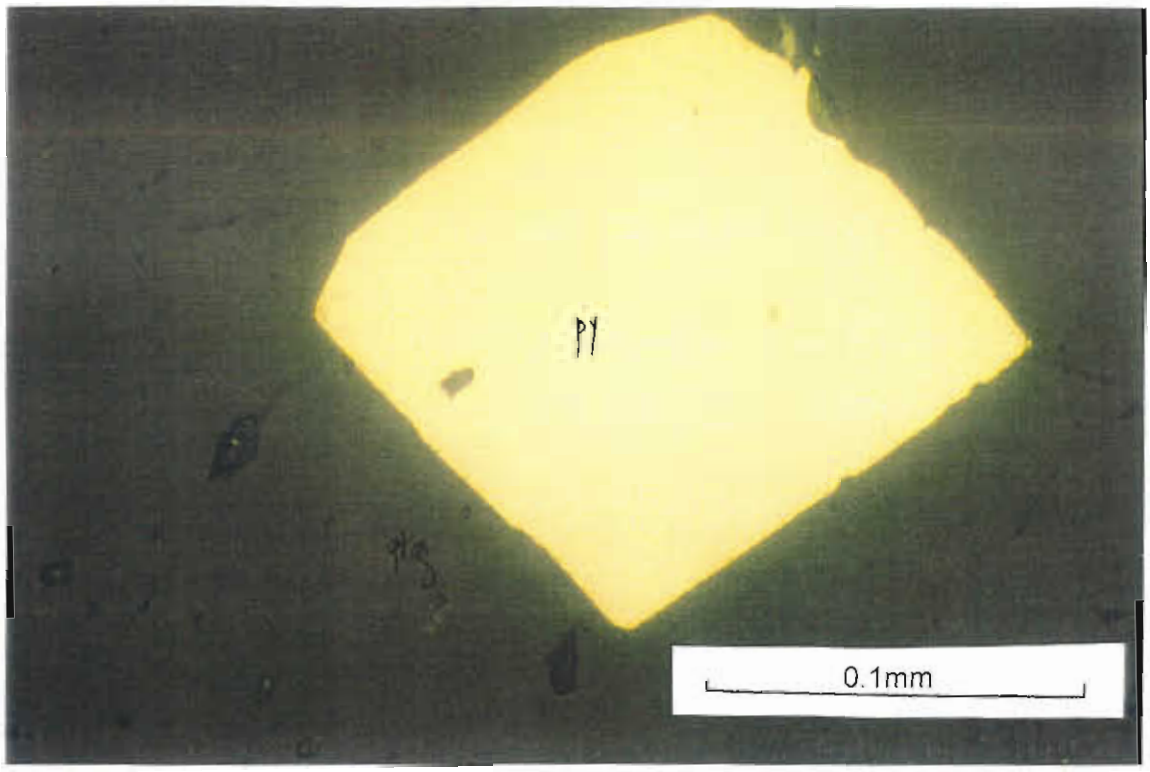
These will not be discussed further.

4.1.2.4 Massive Sulphide Mineralisation

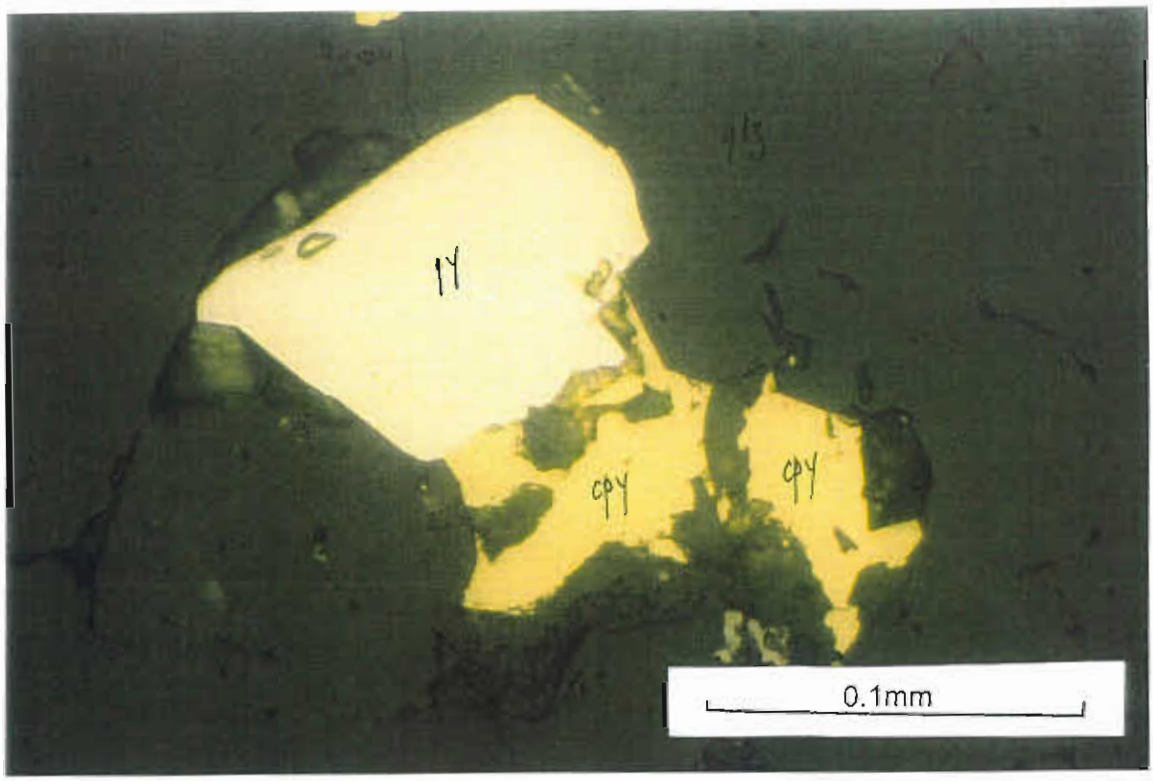
Two fault-controlled bodies of massive sulphides (about 0.5m thick) were observed in drill hole WSD 231 near Waisoi North, comprising dominant (60-70%), 0.5 - 2mm, subhedral, nodular pyrite accompanied by abundant (20-30%), interstitial bornite, with lesser chalcocite, some chalcopyrite, and minor covellite, cubanite, tennantite, electrum and enargite. Copper and gold grades in these zones are approximately 8% and 1.2g/t, respectively.

An examination of polished sections showed over half the gold occurred as 2-25 microns electrum inclusions in deformed quartz grains (Plate 4.8) within the sulphides (Huston, 1992).

A similar massive sulphide structural zone was also noted in drill hole WSD 234.

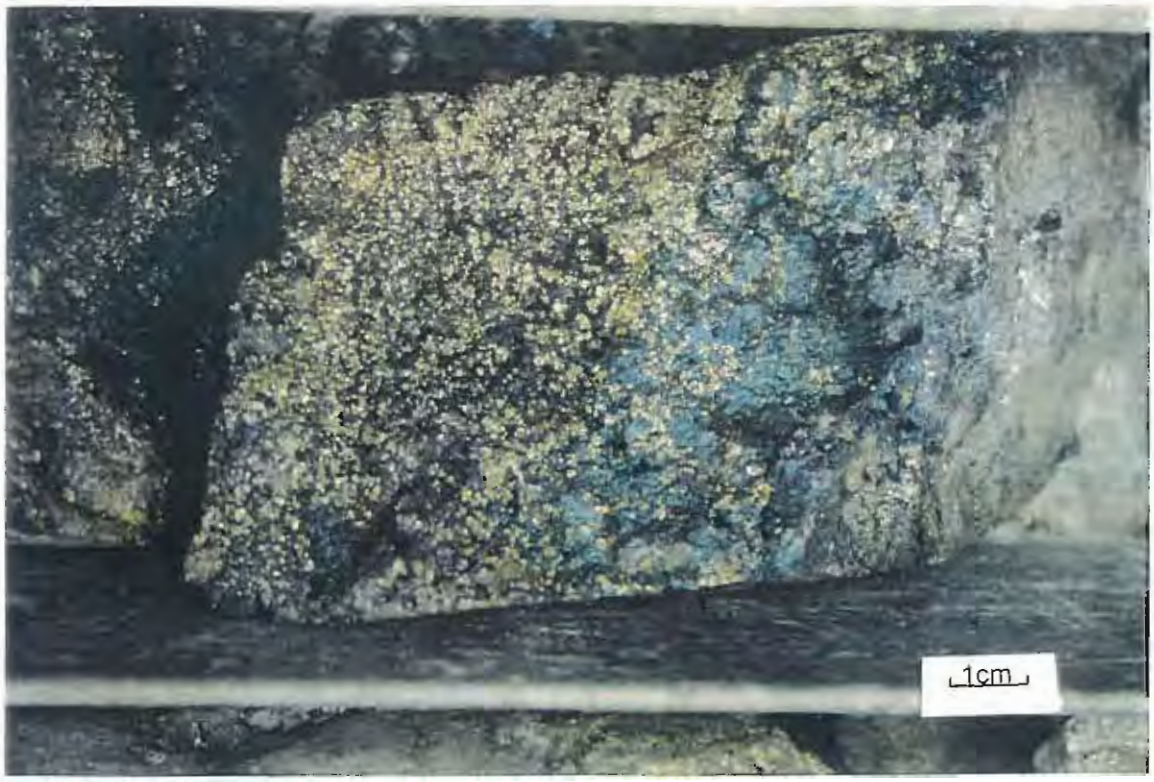


(a) A single pyrite euhedra in quartz (reflected light). WSD 234 - 110.90m



(b) A pyrite euhedral grain with chalcopyrite in quartz (reflected light).
WSD 234 - 110.90m

Plate 4.7 Occurrences of pyrite.



(a) Massive sulphide in which the electrum grains below were located.
WSD 231 - 115.70m

(b) Electrum grain in quartz with bornite (reflected light).

(c) Electrum grain in quartz in bornite with chalcocite and pyrite (reflected light)

Plate 4.8 Electrum grains in the structurally remobilised massive sulphide zone

Within the massive sulphide zones several phases of mineralisation are evident. The dominant core pyrite grains are coated by spongy pyrite overgrowths with the coated grain frequently fractured. These fractures are filled by bornite/chalcocite intergrowths. Within the pyrite are inclusions of electrum and covellite. Late stage quartz - carbonate +/- pyrite micro-veinlets cut the pyrite and bornite grains.

4.1.2.5 Secondary Enrichment

Although secondary enrichment, in the form of a chalcocite blanket, is common in porphyry copper deposits (Gustafson, 1978; Gustafson, 1995) no significant secondary copper enrichment has been located in the Namosi district. Leggo (1977) suggested that at Waisoi there is a leaching of copper from the upper oxidised profile, based on an analysis of the soil geochemistry. This phenomenon is being increasingly recognised at other porphyry deposits (K. Lawrie, pers.comm., 1996), and appears to be related to climatic controls and porphyry systems which have a low sulphur (pyrite) content.

The other factors influencing the occurrence of a chalcocite blanket are

- the occurrence of the main Waisoi mineralisation on the floor of the valley prevents the migration of fluids containing dissolved copper downslope to an outflow zone, and
- the high rainfall (+6m/a) prevents any evaporation from the mineralised areas in the floor of the valley

No further discussion of secondary enrichment will be made, as there is little potential for a significant resource occurring in the vicinity of the Waisoi porphyry mineralisation.

4.2 PROSPECT ALTERATION

4.2.1 General

Throughout the Namosi district both porphyry-related and epithermal alteration is common. The three main areas of significant porphyry mineralisation at Waisoi, Wainabama and Waivaka have zones of hydrothermal alteration extending several kilometres out from the main mineralised zones (Figure 4.1). In each area the style and extent of the alteration varies according to the host rocks, structure, depth of emplacement, and erosion level. At Waisoi, the increased depth of erosion has exposed the porphyries responsible for the mineralisation and alteration. This has uncovered a range of alteration zones which are deeper in the porphyry system than those exposed at Waivaka, where only the upper parts of the system have been eroded (no porphyries exposed) and the alteration has affinities to epithermal systems. The depth of the Wainabama alteration system is part-way between the Waisoi and Waivaka systems.

Mineralisation and alteration at Waisoi occur at the contact between the Wainimala basement and the Namosi Andesite, while at Waivaka the altered rocks are the Namosi Andesite lavas and volcaniclastics. The variety of host rocks has led to different alteration assemblages being present at the two porphyry systems. At Waivaka the widespread, pervasive, porphyry-related alteration ("regional alteration") is dominated by sericite which is truncated at depth by anhydrite, whereas at Waisoi the "regional alteration" is dominated by chlorite, with no anhydride.

Significant zones of hydrothermally altered rocks occur in the vicinity of most of the geochemical anomalies shown in Figure 4.2. Hydrothermal alteration also occurs in areas with minor to no geochemical anomalies (Figure 4.2), such as:

- Nowai - where boulders and outcrop of quartz/alunite altered-volcanics occur over a wide area,
- Wainikana - where an extensive area of chlorite/epidote/magnetite alteration occurs to the east of the Waivaka alteration and mineralisation

The only alteration to be examined in more detail will be that occurring within the Waisoi porphyry copper +/- gold deposits.

4.2.2 Waisoi Alteration

At Waisoi alteration has resulted from a regional metamorphic event and a porphyry-related hydrothermal event. From geological evidence it has been determined that the regional metamorphism occurred significantly earlier than the hydrothermal alteration.

The results of regional metamorphism are widespread throughout the basement rocks of southeast Viti Levu, whereas the hydrothermal alteration is associated with quartz dioritic intrusives into calc-alkaline volcanics. The two styles of alteration are considered separately.

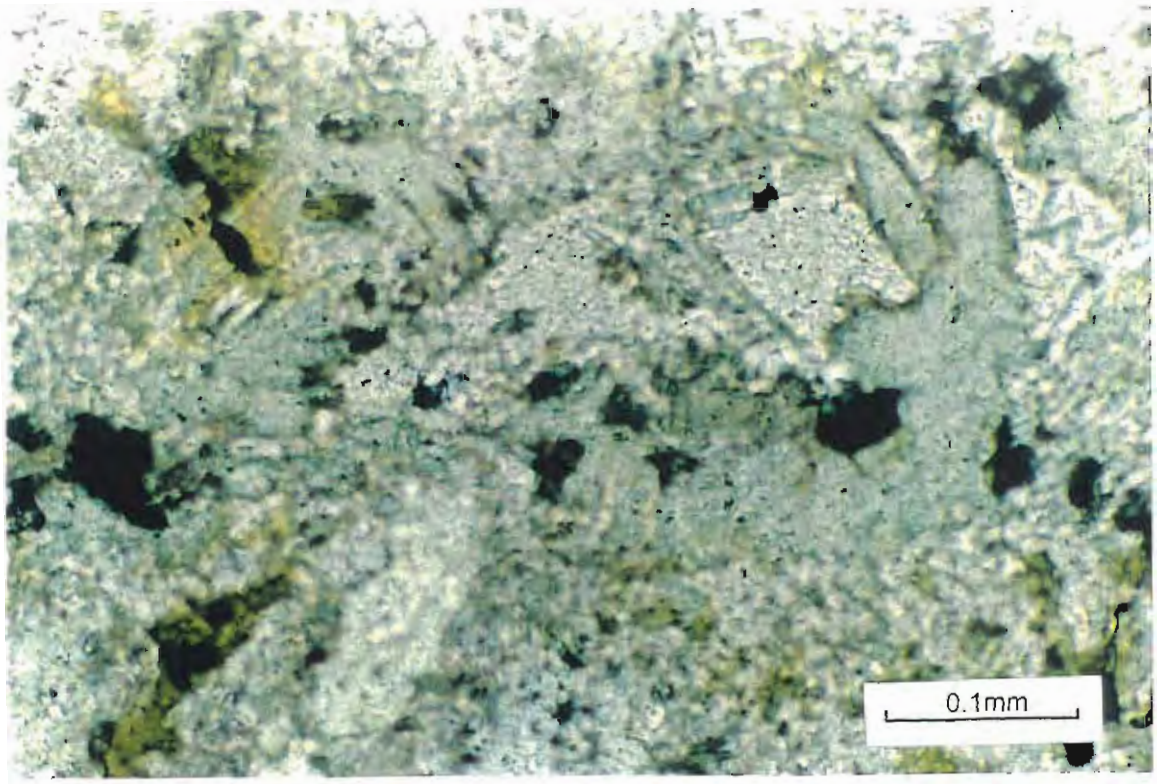
4.2.2.1 Regional Burial Metamorphism

The only rocks that show significant effects of regional burial metamorphism are the lavas and volcaniclastics of the Wainimala Agglomerate. These rocks have been metamorphosed to greenschist facies assemblages consisting dominantly of actinolite and biotite (Plate 4.9), but with albite and chlorite also present.

In cores of the least altered fragments of the Wainimala Agglomerate abundant colourless to very pale green actinolite occurs as fine-grained, fibrous to acicular crystals and patches of crystal aggregates, some of which are intergrown with fine-grained, brown, strongly pleochroic biotite (Plate 4.9). Some of the biotite appears to be recrystallised chlorite, which implies a regional metamorphic temperature of around 300^0C. In places, some of the biotite occurs as dense mats of intergrown crystals, sometimes with subordinate, colourless to pale green, bladed chlorite crystals.

In many samples of the Wainimala Agglomerate volcanics, the plagioclase phenocrysts and parts of the fine-grained, glassy groundmass, have been almost totally replaced with fine-grained, acicular albite (albitisation). This albite is often intergrown with quartz (Plate 4.10) and riddled by actinolite needles.

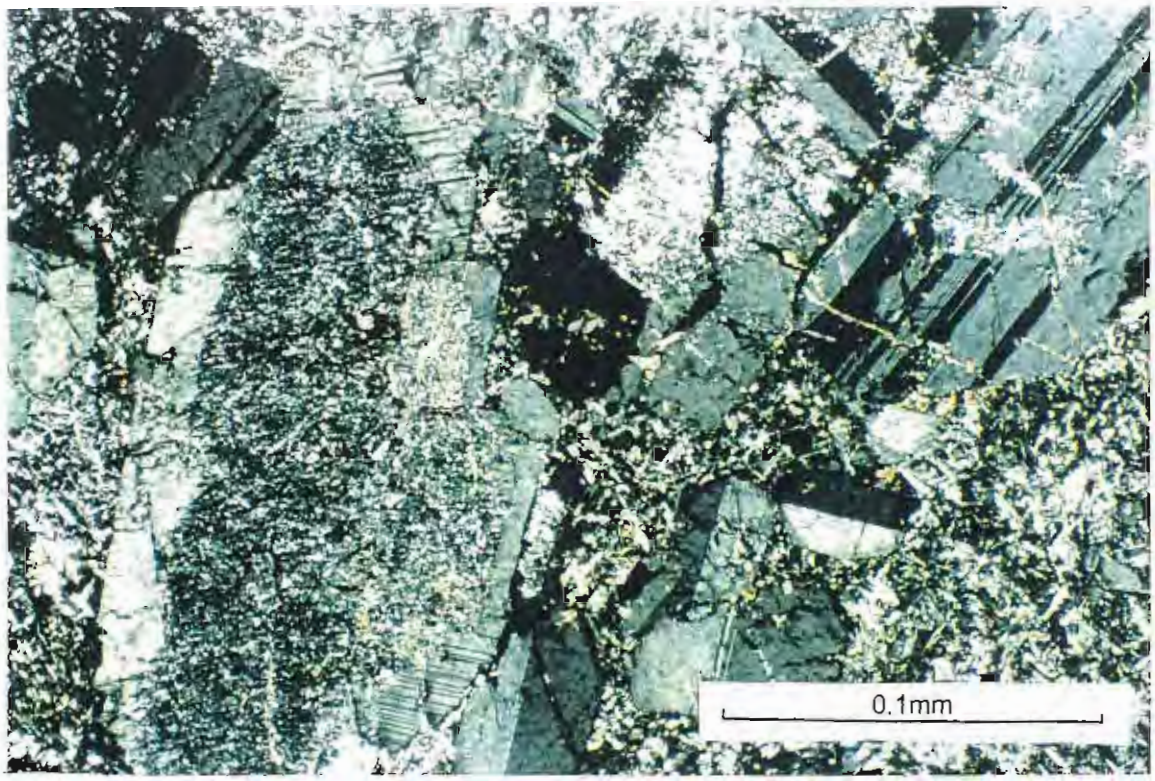
(a) Actinolite, biotite and sericite overprinted by albite and being cut by a sulphide-rich vein, including bornite and digenite (crossed nicols).
WSD 212 - 235.00m



(b) Quartz and actinolite with minor sericite overprinted by calcite (plain light) WSD212 - 330.50m

Plate 4.9 Regional burial metamorphic assemblages.

(a) Pervasive albite alteration with biotite and sericite (crossed nicols).
WSD 212 - 235.00m



(b) Plagioclase phenocrysts altered by quartz and albite (crossed nicols).
WSD 228 - 320.75m

Plate 4.10 Albite altered Wainimala Agglomerate.

Minor occurrences of radiating crystal fans and blades of epidote associated with the actinolite-biotite-albite-chlorite alteration are also related to the regional burial metamorphism event.

4.2.2.2 Porphyry-related Hydrothermal Alteration

The porphyry-related alteration mineralogy in the Waisoi area was identified, and its distribution delineated, during geological mapping, drill core logging and thin section studies.

The geological mapping showed that although the Waisoi porphyry-style alteration is centred about the P1 and P4 contemporaneous intrusions, alteration extends outwards for at least 4km. These porphyries have both disseminated and veinlet related alteration, which is controlled by a network of micro-veinlets and fractures concentrated in the cupola region of the intrusives and the brecciated haloes surrounding the intrusives.

4.2.2.2.1 General Distribution

The alteration at Waisoi is directly controlled by the distribution of the porphyry intrusions (Figures 3.4 to 3.9). Hydrothermal fluids have migrated outwards from the porphyry contacts, and caused alteration of all rock-types, including the porphyries, during several phases of fluid flow.

In general, the cores of the porphyries around Waisoi tend to be low-grade, silicified zones of intense fine- to coarse-grained quartz veins and/or pervasive silicification. These silicic cores are surrounded by zones of porphyry which have undergone pervasive clay and sericite alteration with only minor chloritisation. The outer zones of the porphyries are albite-sericite-quartz-clay-rich with some biotite, pyrophyllite and minor corundum (Ellis, 1991). Within the porphyries, the alteration is pervasive, with some later, alteration (mainly sericite and K feldspar) along quartz veinlets.

Within the Wainimala Agglomerate alteration is controlled by micro-fractures. The intrusion of the porphyries (and earlier regional structural events) resulted in shattering of the brittle, greenschist-metamorphosed volcanics. Fluids from the porphyries moved through the resultant micro-fractures causing alteration.

Distal to the porphyries the Wainimala Agglomerate is dominantly chlorite-pyrite-silica ± epidote ± calcite altered, giving the rock the appearance of an agglomerate to conglomerate (from which came the local agglomerate name of the unit). With increasing alteration intensity (closer to the porphyries), the Wainimala Agglomerate is pervasively altered by chlorite-pyrite-quartz, and chlorite spots start to develop. Closer to the porphyry contact, pyrite and chlorite are replaced by magnetite and biotite and finally, at or near the porphyry contact, K feldspar and/or sericite ± clay is dominant. The presence of abundant biotite and/or K feldspar within the Wainimala Agglomerate, also appears to be related to an increase in the bornite content and to the proximity of porphyry intrusions.

Alteration within the Wainimala Agglomerate tends to be caused by the chemical dis-equilibrium between the fluids from the intrusives (chemically similar to the Namosi Andesite andesitic dacites) and the chemically different basaltic to andesitic lavas of the Wainimala Agglomerate.

The Namosi Andesite alteration is significantly different to that of the underlying Wainimala Agglomerate. Generally, the Namosi Andesite alteration is pervasive rather than fracture-controlled. In the outer zone (more distal from the intrusives) the formerly glassy (now devitrified) Namosi Andesite lavas have been pervasively epidote-calcite-pyrite altered. Inward, this changes to quartz-sericite ± pyrite and then to sericite -magnetite, with greatly increased chlorite. Closer to the porphyry, biotite increases relative to chlorite until biotite is the dominant mafic alteration mineral. K-feldspar and quartz also increase until the feldspar is replaced by sericite and/or clay in the Namosi Andesites adjacent to the porphyry contact.

Hydrothermal alteration of the Basal Namosi Conglomerate shows similarities to the alteration of the Wainimala Agglomerate and the Namosi Andesite. In the lower units, composed mainly of basement derived fragments, the Basal Namosi Conglomerate shows a zoning from distal, fracture-controlled, chlorite-pyrite-silica ± epidote ± calcite, changing inward to chlorite-pyrite-quartz with chlorite spots, then to biotite-magnetite-quartz, to a feldspar and/or sericite ± clay altered zone adjacent to the porphyry contact (i.e. similar to alteration zoning of

the Wainimala Agglomerate). Similarly, in the upper units of the Basal Namosi Conglomerate, dominated by Namosi Andesite derived fragments, the alteration shows a zoning from distal, pervasive, epidote-calcite-pyrite, inward to quartz-sericite ± pyrite, to sericite -magnetite-chlorite, to biotite-K-feldspar-quartz, to a sericite and/or clay zone adjacent to the porphyry contact (i.e. similar to the alteration zoning of the Namosi Andesite).

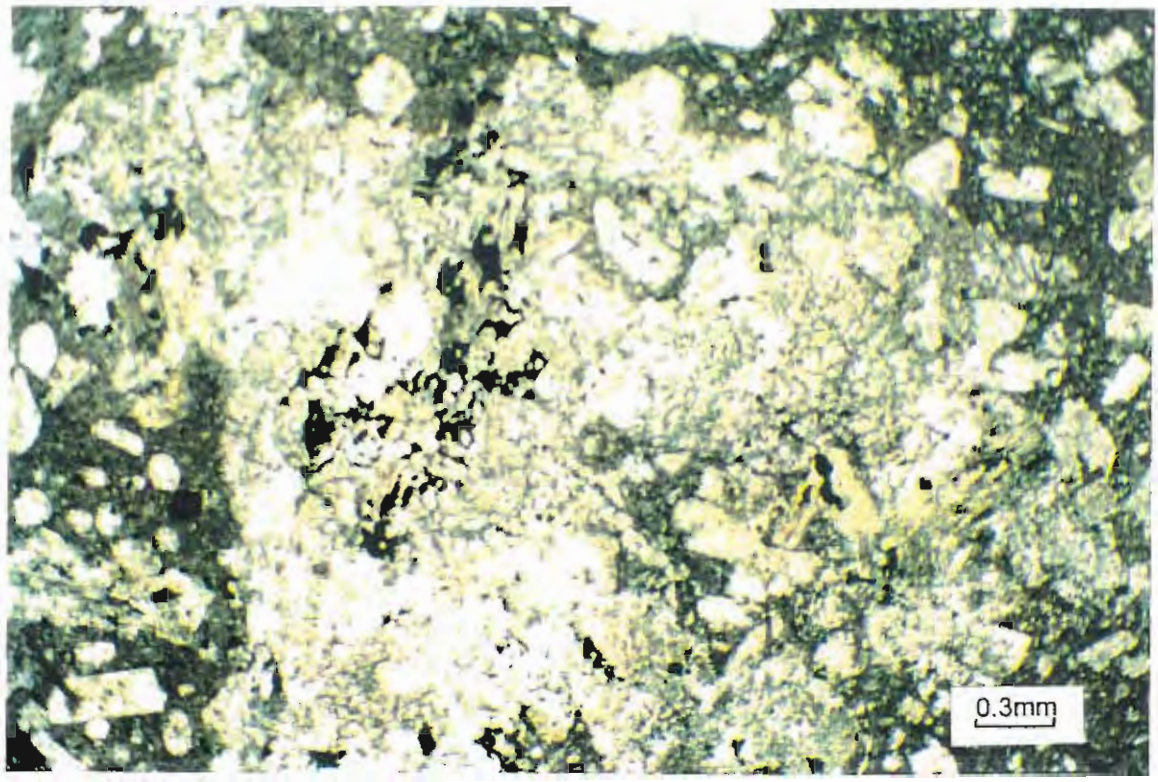
However, the grain size and/or composition variability of the fragments in the Basal Namosi Conglomerate locally changes the alteration/ mineralisation patterns. Within the conglomerate (and with increasing influence higher in the unit) the felsic volcanic fragments appear to be "tighter" and less altered than adjacent more mafic, shattered, volcanic fragments. The mafic volcanic fragments thus appear more intensely altered than adjacent, more felsic fragments (Plate 4.11).

An alteration assemblage of albite-sericite-yellow epidote+/-chlorite+/-magnetite+/-prehnite in the matrix of parts of the Basal Namosi Conglomerate suggests these rocks have undergone sub-greenschist facies regional metamorphism. Such metamorphism/alteration is probably associated with intrusives related to the extrusion of the main Namosi Andesite lavas. Neither the underlying, greenschist facies Wainimala Agglomerate nor the overlying Namosi Andesite show a similar alteration assemblage.

Overprinting the main porphyry alteration is a later carbonate-rich assemblage which introduced calcite and epidote while destroying bornite, biotite and K-feldspar. This carbonate event has been overprinted by polycrystalline quartz veining and silica alteration.

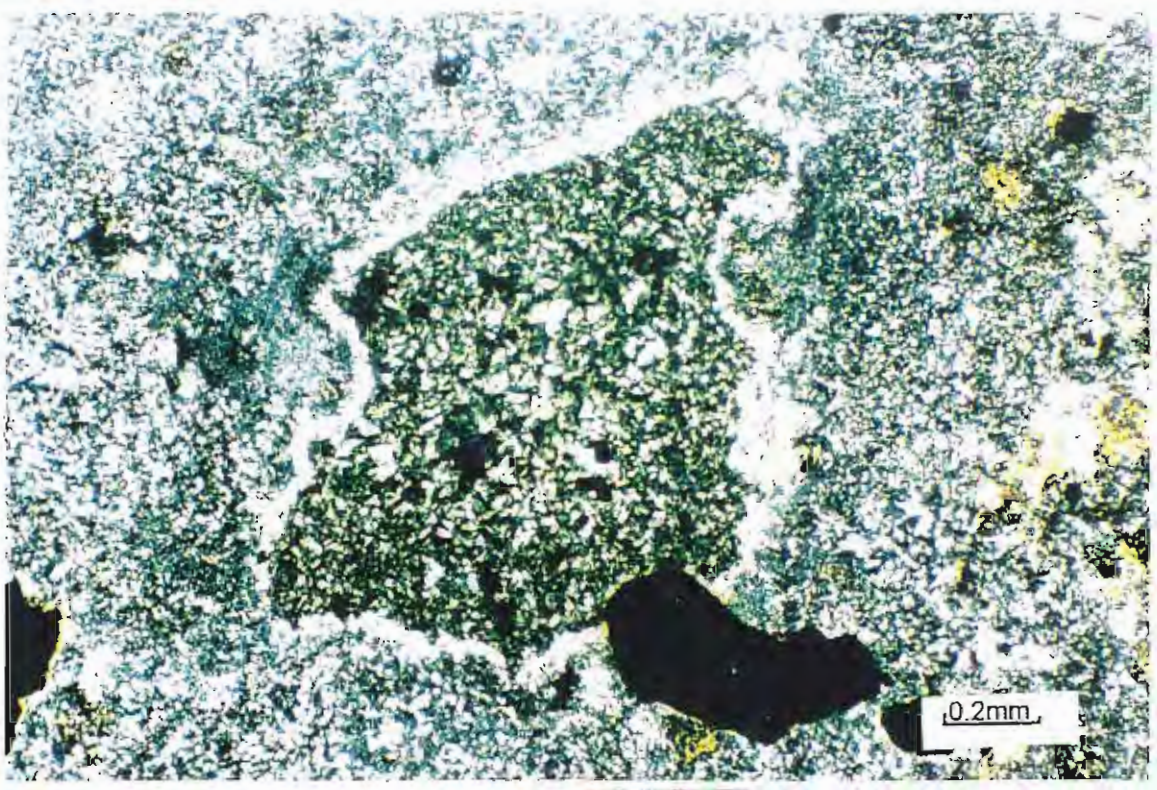
Almost all types and phases of alteration are associated with quartz, sulphides and magnetite, while chlorite and sericite are also ubiquitous. Calcite and epidote are generally associated with the later stages, while actinolite is associated with very early alteration stages. These will be discussed in more detail when considering the paragenesis of the alteration.

In a broad sense, alteration and mineralisation tends to extend laterally in the Basal Namosi Conglomerate and upper Wainimala Agglomerate horizons,



(a) "Fresh" felsic fragment in a chlorite-quartz altered matrix (plain light).

WSD 217 - 360.60m



(b) Re-action rim around a more felsic fragment within a quartz-albite-sericite+/- chlorite altered matrix (crossed nicols).

WSD 81 - 97.00m

Plate 4.11 Alteration of the Basal Namosi Agglomerate.

apparently as a result of the sealing of fluid pathways by the less permeable Namosi Andesite.

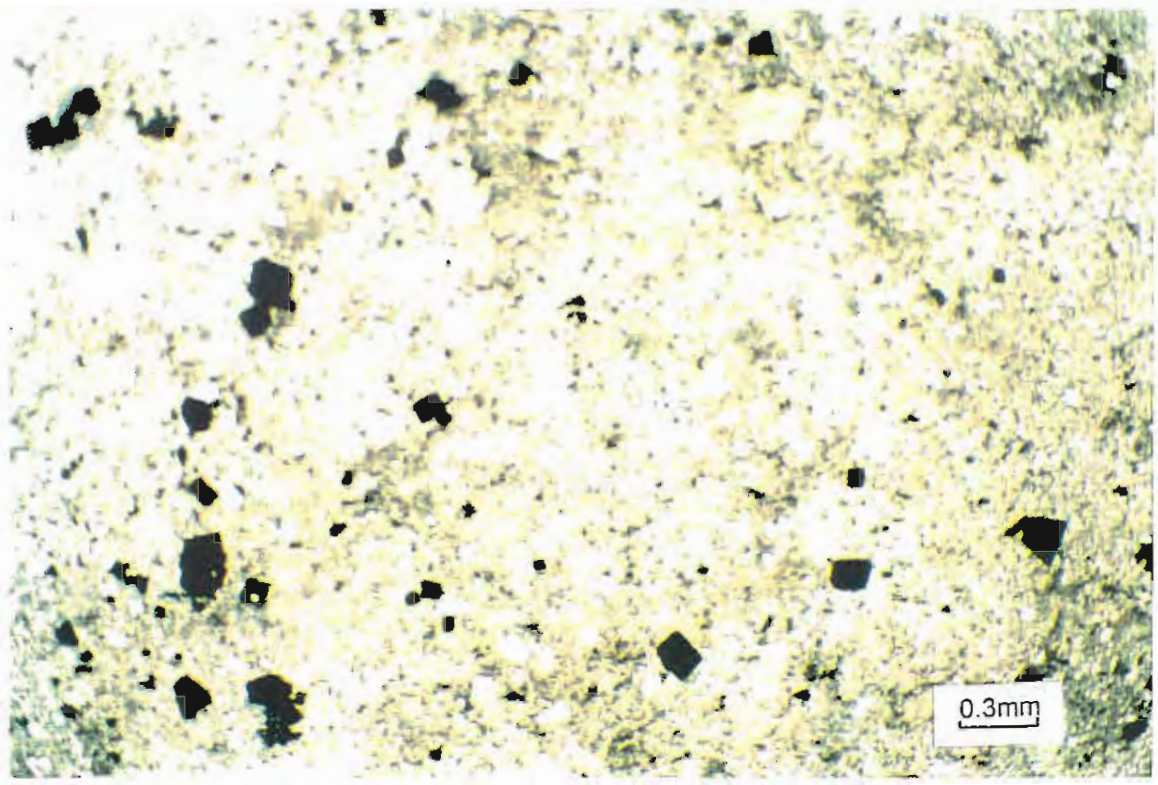
4.2.2.2.2 Disseminated Alteration

Disseminated alteration is widespread throughout much of the Waisoi porphyry system. Disseminated alteration occurs as zones of concentrations of dominantly fine-grained, anhedral to subhedral chlorite, magnetite, haematite, K-feldspar, quartz, biotite, albite, pyrite and epidote (Plate 4.12).

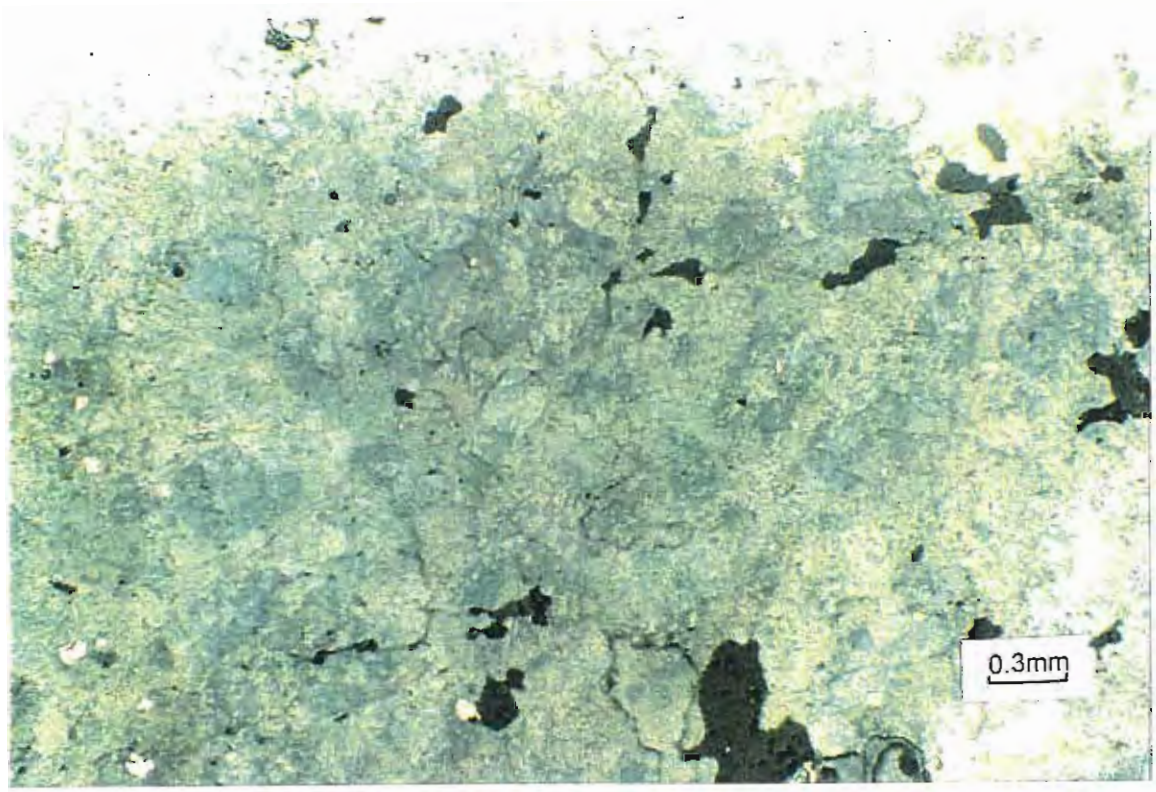
The most common mineral is chlorite, which occurs as clots around large, anhedral magnetite and/or pyrite grains, particularly in the vicinity of silica/chlorite veins within both the Wainimala Agglomerate and the Namosi Andesite (Plate 4.13). Zoned chlorite to sericite clots and blebs up to 6mm also occur, particularly in the Namosi Andesite. Where chlorite forms zones of disseminated crystals, there is a common association with patches of fine-grained, anhedral epidote and magnetite. Elsewhere epidote occurs as irregular spots and aggregates of bright yellow crystals, some of which form fibrous fans.

Disseminated pyrite is associated with almost all alteration assemblages. Pyrite occurs as scattered, euhedral, idiomorphic crystals (some resorbed edges) up to 1mm (Plate 4.14), although some zones of aggregates of crystals occur. The crystals occur in a variety of ways, including tiny inclusions within plagioclase phenocrysts, aligned along rock fractures, and associated with sericitised plagioclase in the groundmass of volcanics.

Magnetite (some oxidised to haematite) is almost as common as pyrite and occurs as equi-dimensional, fine-grained, often irregular shaped, ragged grains (Plate 4.15) concentrated in diffuse, patchy zones of aggregates up to 5mm long. The magnetite aggregates are commonly intergrown with chlorite and streaked through the groundmass of the volcanics, particularly the Wainimala Agglomerate. Adjacent to quartz veining, the scattered magnetite grains in the groundmass often become more densely distributed.

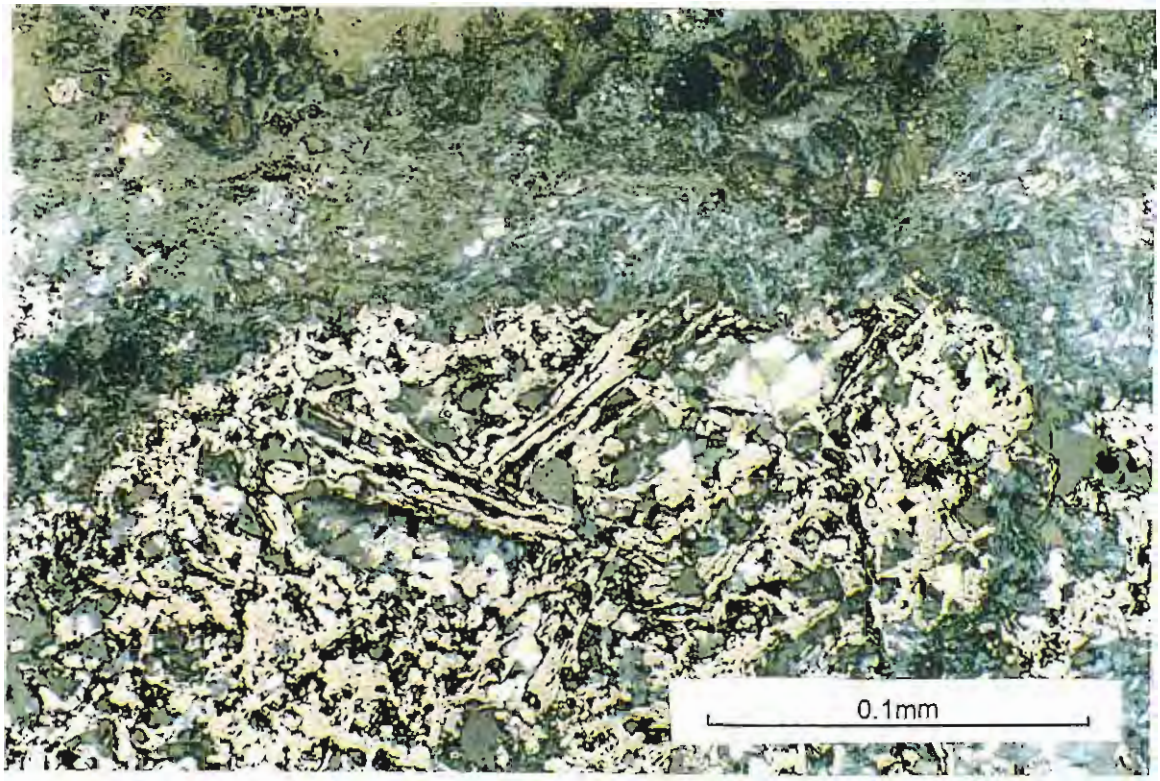


(a) Disseminated grains of pyrite and quartz in the Namosi Andesite (plain light). WSD 217 - 70.00m

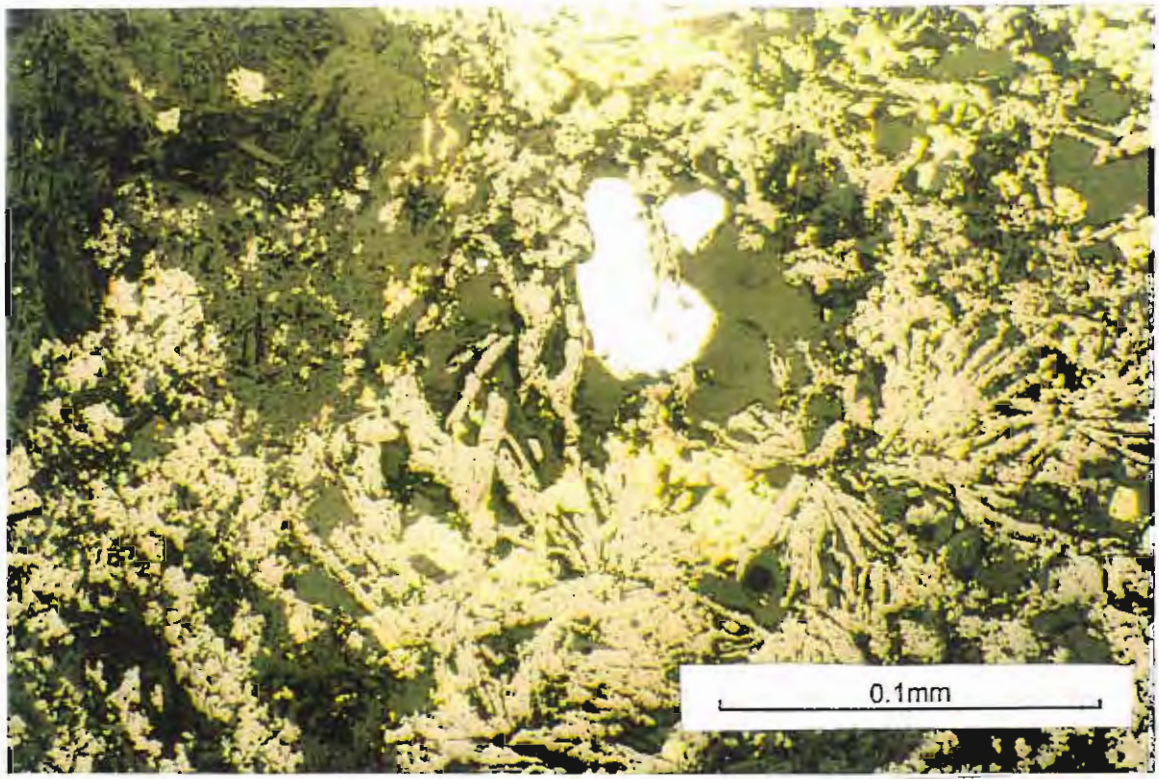


(b) Disseminated grains of magnetite and pyrite adjacent to a quartz veinlet (reflected light) WSD 241 - 48.05m

Plate 4.12 Disseminated Alteration.

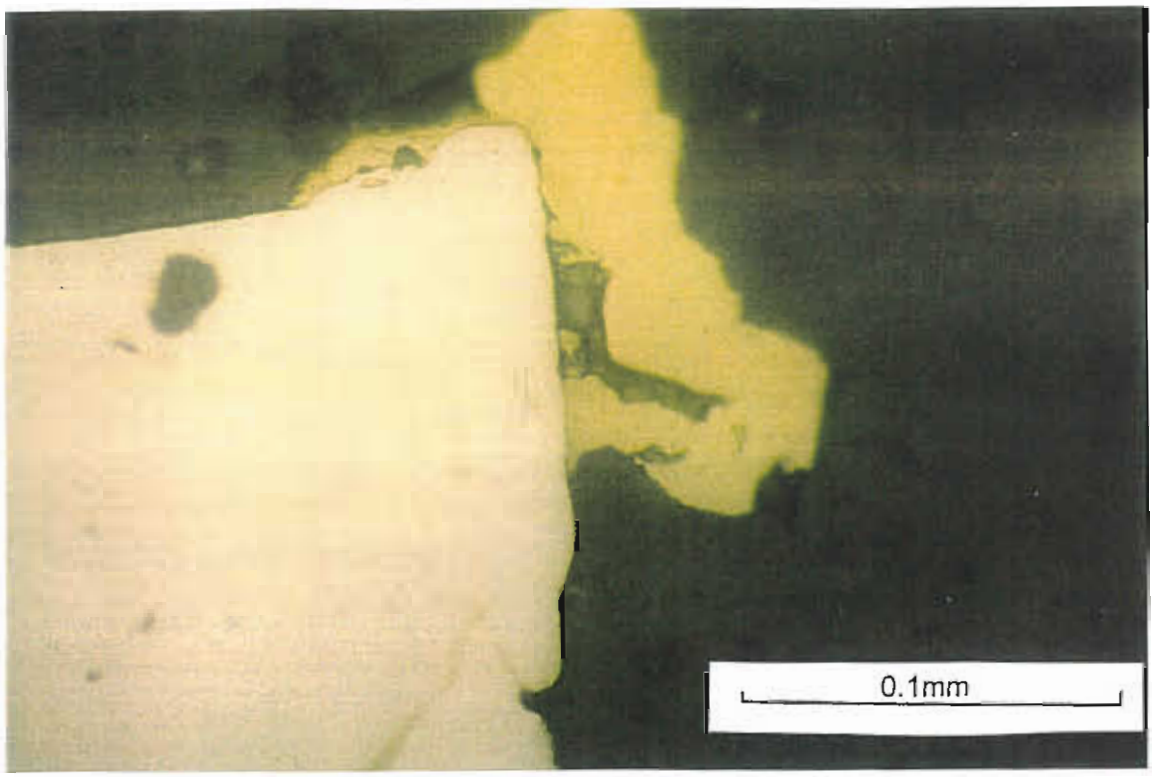


(a) Eroded magnetite grain in a zone of chlorite concentration (reflected and crossed nicols). WSD 228 - 117.40m

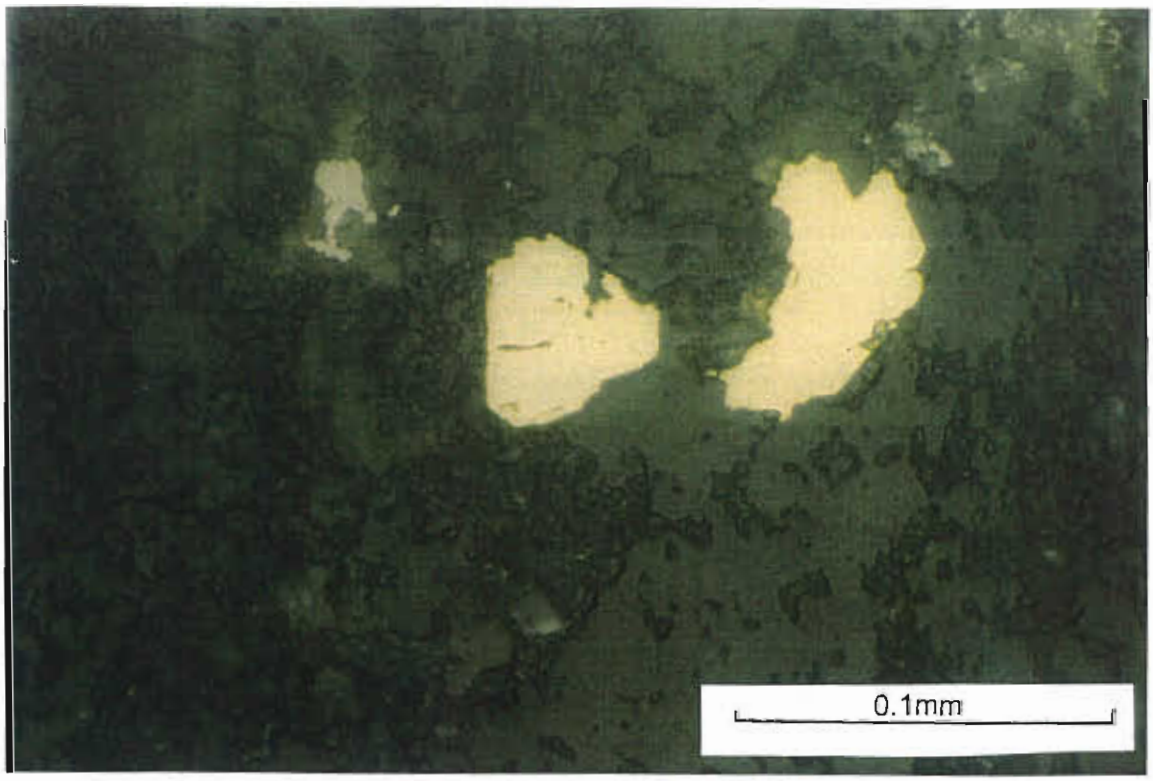


(b) Pyrite grain at the centre of a zone of chlorite concentration (reflected light). WSD 241 - 48.05m

Plate 4.13 Chlorite clots.

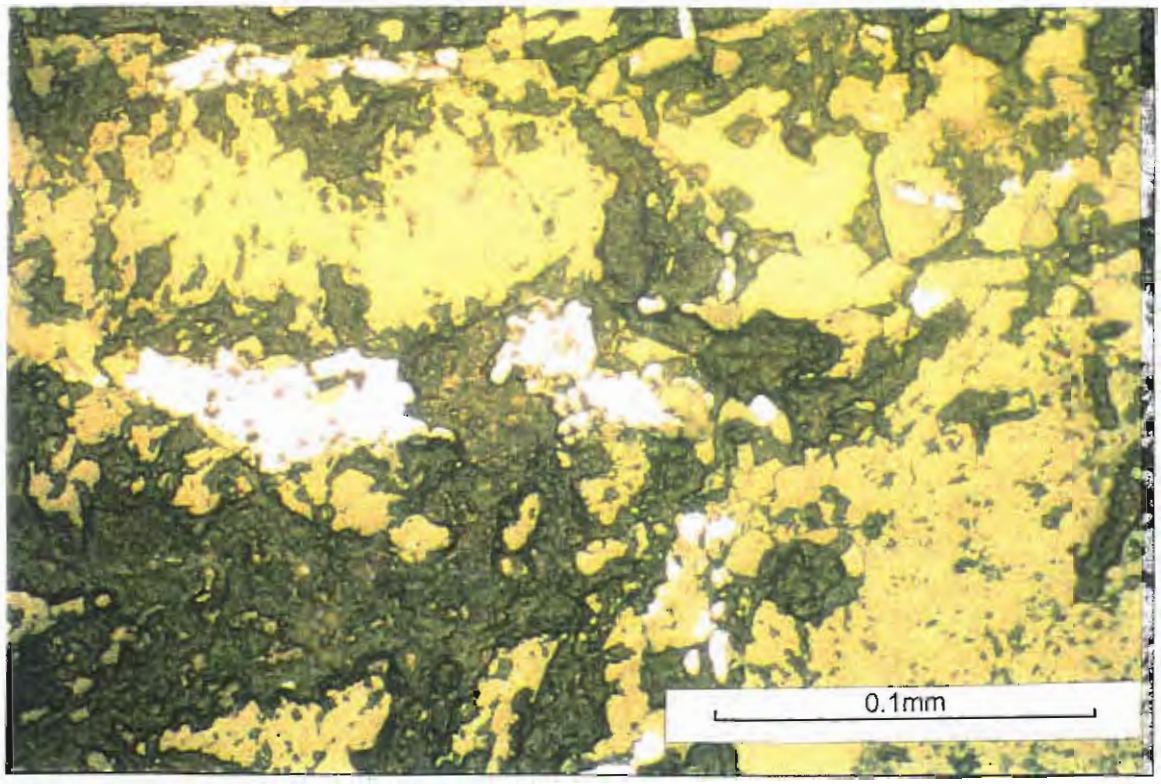


(a) Euhedral pyrite grain being overgrown by chalcopyrite (reflected light).
WSD 225 - 73.50m

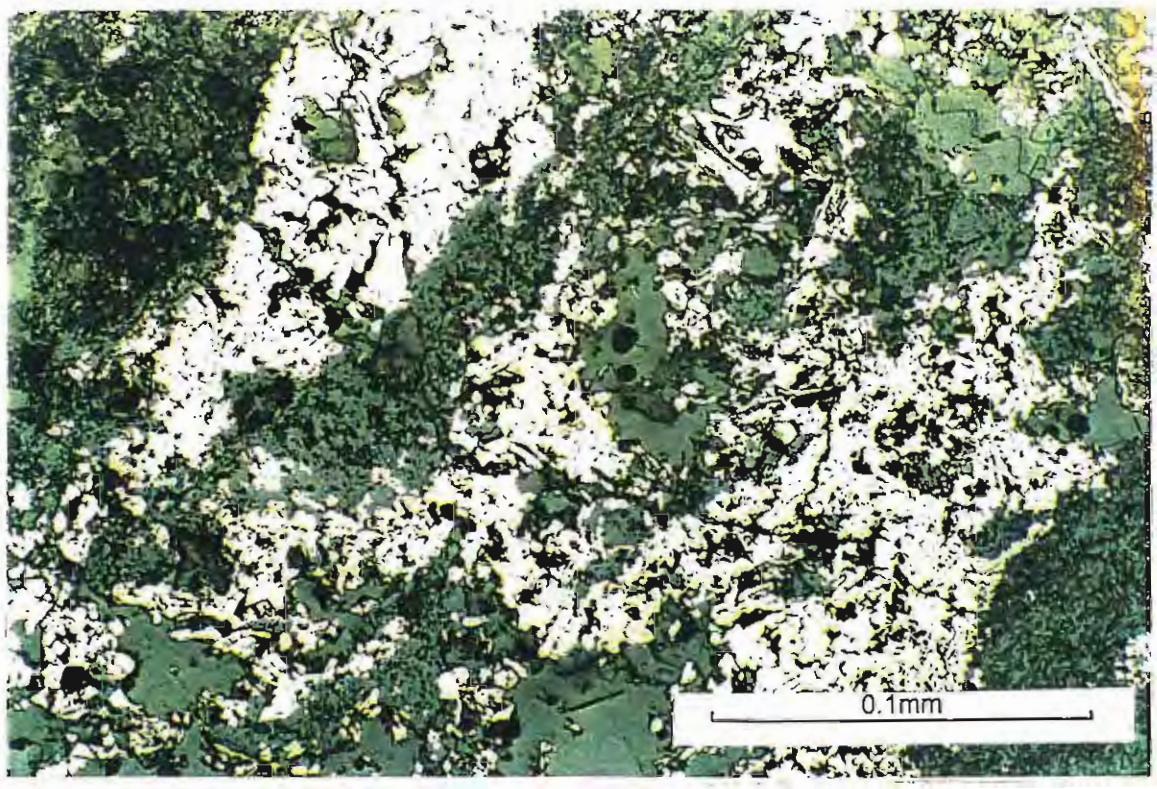


(b) Disseminated pyrite grains showing some resorbtion (reflected light).
WSD 234 - 110.90m

Plate 4.14 Disseminated pyrite.



(a) Irregular shaped, ragged magnetite grains in the Namosi Andesite (reflected light). WSD 228 - 117.40m



(b) Irregular magnetite grains being corroded and replaced by pyrite (reflected light). WSD 228 - 117.40m

Plate 4.15 Disseminated magnetite.

Other disseminated alteration minerals from the Waisoi porphyry system occur only rarely. These include:

- K-feldspar which occurs as fine-grained, anhedral crystals that are often sericitised,
- quartz which occurs as polygonal, coarse-grained crystal, commonly associated with minor sulphides,
- biotite which occurs as very minor, dark brown, strongly pleochroic, fine-grained, isolated crystals, and
- albite which occurs as subhedral, mainly sericitised zones, some of which rim plagioclase phenocrysts

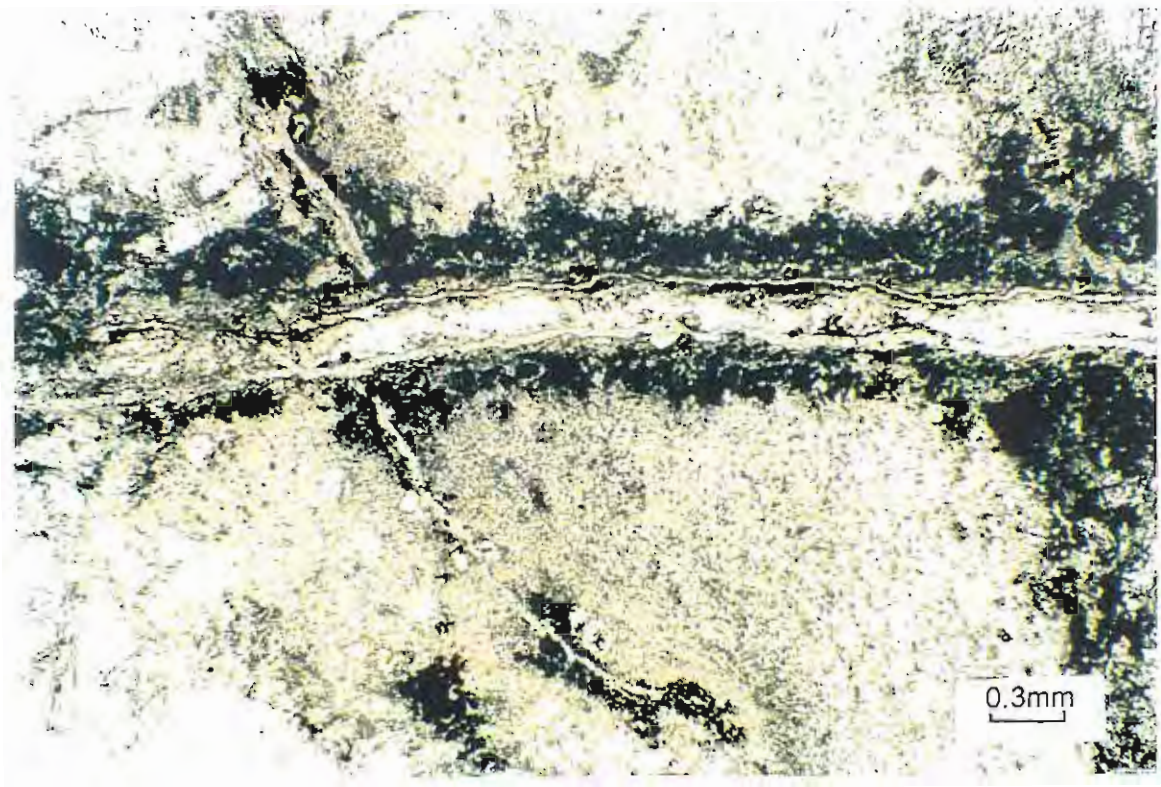
These forms of disseminated alteration will not be discussed further.

4.2.2.2.3 Vein Alteration

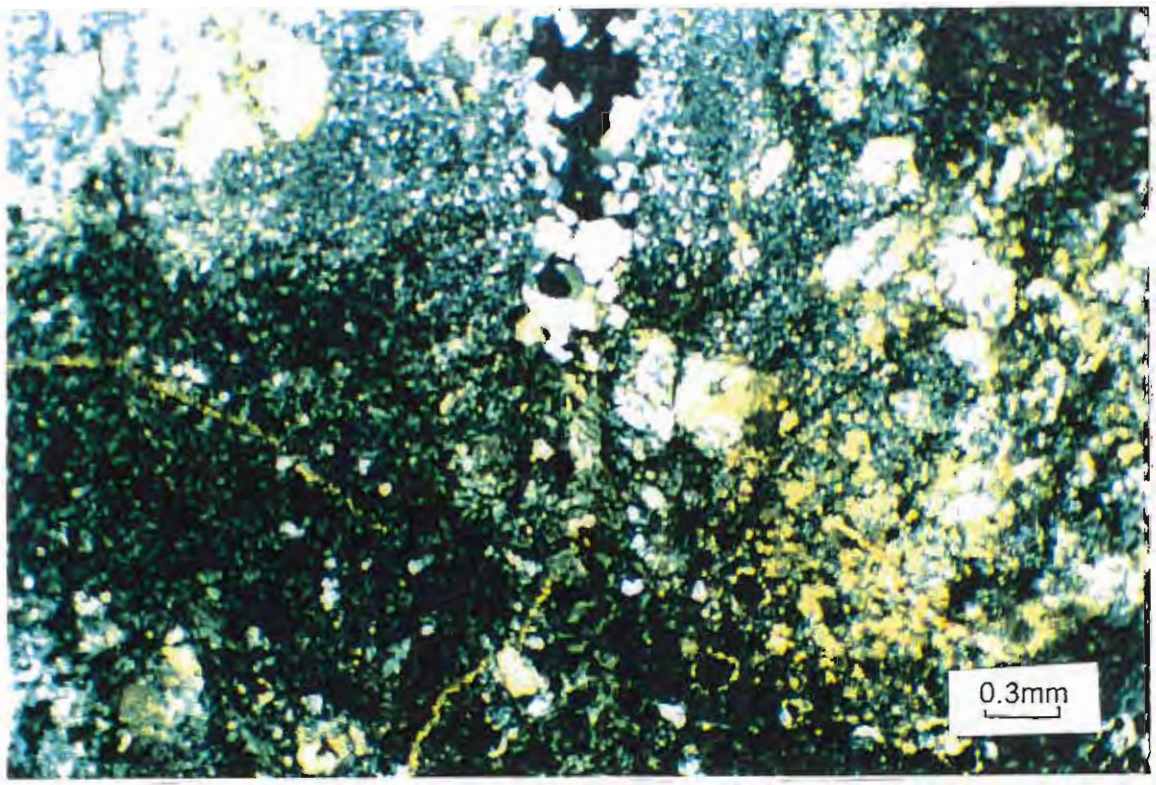
Alteration associated with veining is abundant in the Waisoi porphyry copper/gold deposit, particularly in the Wainimala Agglomerate and the Basal Namosi Conglomerate units. Significantly fewer veins and veinlets are observed in the Namosi Andesite. This reflects the brittle nature of the Wainimala Agglomerate and the high proportion of open-space in the Basal Namosi Conglomerate, compared to the high proportion of microscopic permeability and porosity in the Namosi Andesite, where pervasive alteration is more common. Most of the veins are less than 2cm across, and commonly less than 1mm. Effects of vein alteration are clearly visible up to several centimetres away from the veins and veinlets (Plate 4.16). In general, almost all the alteration and mineralisation at Waisoi is related to fracture controlled fluid pathways.

The earliest vein alteration noted at Waisoi occurs in the greenschist-facies Wainimala Agglomerate, where rare quartz/actinolite veinlets cut the lavas (Plate 4.9b). These contain coarse-grained actinolite crystals intergrown with coarse-grained quartz.

The most common vein-related alteration mineral is quartz, which occurs as polygonal, sugary, fine- to coarse-grained, crystals up to 1cm across (but commonly less than 1mm) forming quartz-rich veins (Plate 4.4). Quartz veins appear to occur throughout the life of the Waisoi porphyry system as some of



(a) Sulphide grains cut by later stage calcite vein which shows zoning and a pervasive chlorite alteration (reflected light) WSD 212 - 355.30m



(b) Quartz-actinolite vein surrounded by pervasive quartz-albite-actinolite alteration cut by a calcite-quartz vein with pervasive chlorite alteration (crossed nicols). WSD 234 - 106.60m

Plate 4.16 Pervasive alteration adjacent to veins.

the earliest phases appear as structurally disrupted (broken, shattered and disjointed) quartz veins, while the late-stage carbonate veins also contain quartz. The quartz grains are intergrown with minor sulphides +/- fine-grained magnetite/haematite, along intimately-sutured grain boundaries. Commonly the quartz veins contain separate sulphide grains, in particular chalcopyrite, bornite and, to a lesser extent, covellite, digenite and chalcocite. In limited areas (such as the Waisoi West ridge area) the quartz veins +/- sulphides occur as cross-cutting vein stockworks. In the perimeter areas of the porphyries quartz vein stockworks are often associated with sulphides, forming pods of higher-grade copper mineralisation.

Thin veins of fine-grained quartz and chlorite intergrowths, associated with widespread chloritisation, commonly occur throughout the Waisoi porphyry system.

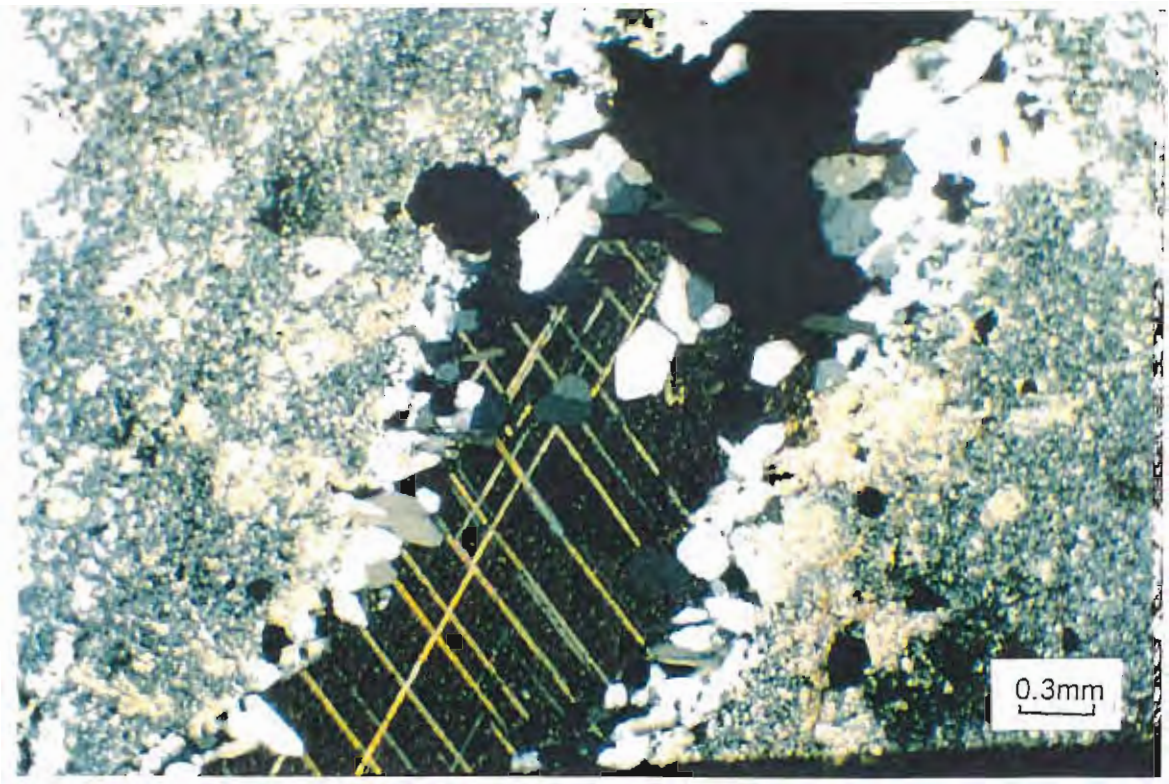
Rare thin veinlets containing fine-grained quartz with very fine-grained albite occur in the Wainimala Agglomerate.

Minor occurrences of veins of coarse-grained quartz crystals intergrown with anhedral pyrite and prismatic barite have been observed. These veins are associated with pervasive quartz/sericite alteration.

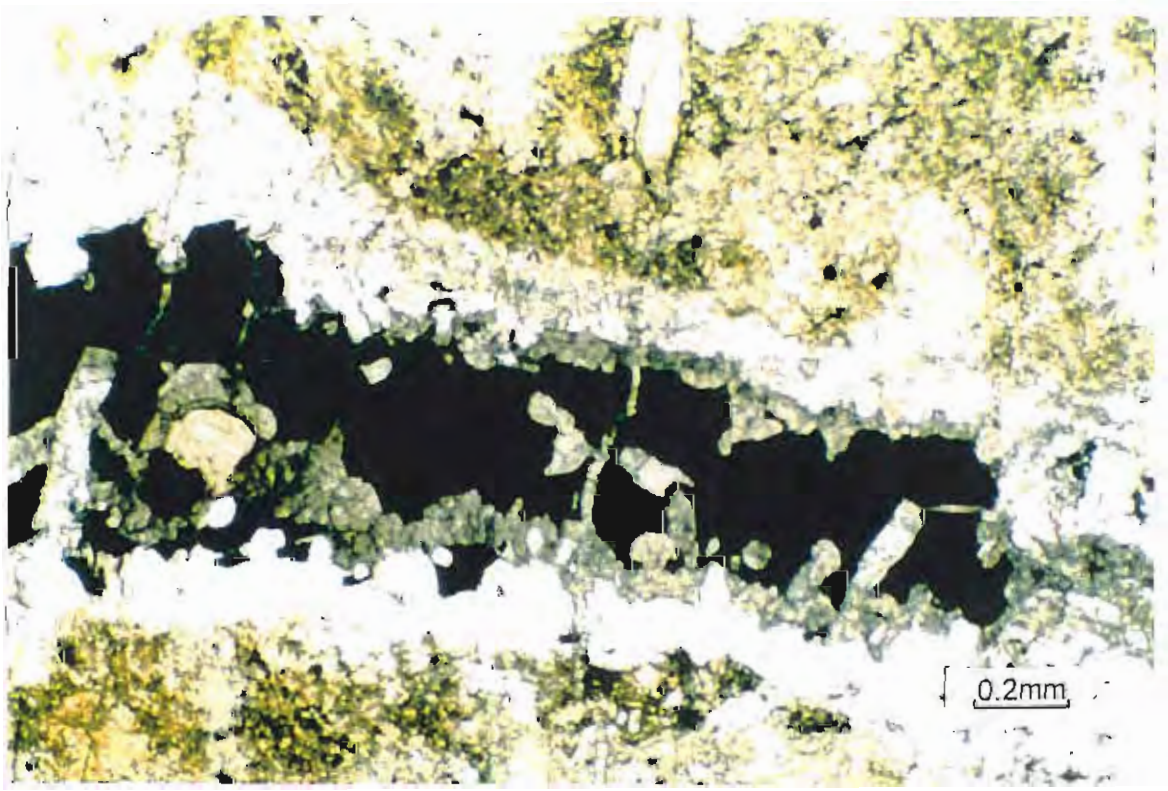
Quartz is also commonly associated with calcite-rich, late-stage veins, although there appears to be a very late stage of calcite only veining. The carbonate veins contain coarse-grained, ragged-edged, polycrystalline quartz and coarse-grained, subhedral, brownish rhombs of calcite and are surrounded by pervasive calcite alteration extending outwards for few millimetres (Plate 4.17).

Some calcite veins with minor fine-grained magnetite cross-cut coarse-grained, ragged-edged polycrystalline quartz veins.

Extremely fine-grained magnetite also occurs along micro-shears and may represent pressure solution along high-strain zones. These commonly occur in zones of more intense, higher-grade, bornite mineralisation, usually close to fluid pathways.



(a) Zoned quartz-carbonate-sulphide vein with pervasive calcite alteration (crossed nicols). WSD 217 - 66.15m



(b) Complex sulphide-calcite-quartz vein cut by calcite veinlets with weak pervasive calcite alteration (plain light). WSD 217 - 265.50m

Plate 4.17 Carbonate alteration.

Rare thin veinlets with quartz intergrown with chlorite, stilpnomelane and minor calcite are of uncertain origin but seem to be associated with more intense K-metasomatism, where pervasive bornite is more abundant.

A few distinctive rare veins containing polycrystalline quartz intergrown with calcite, magnetite and coarse analcime have been observed, but their associations are uncertain.

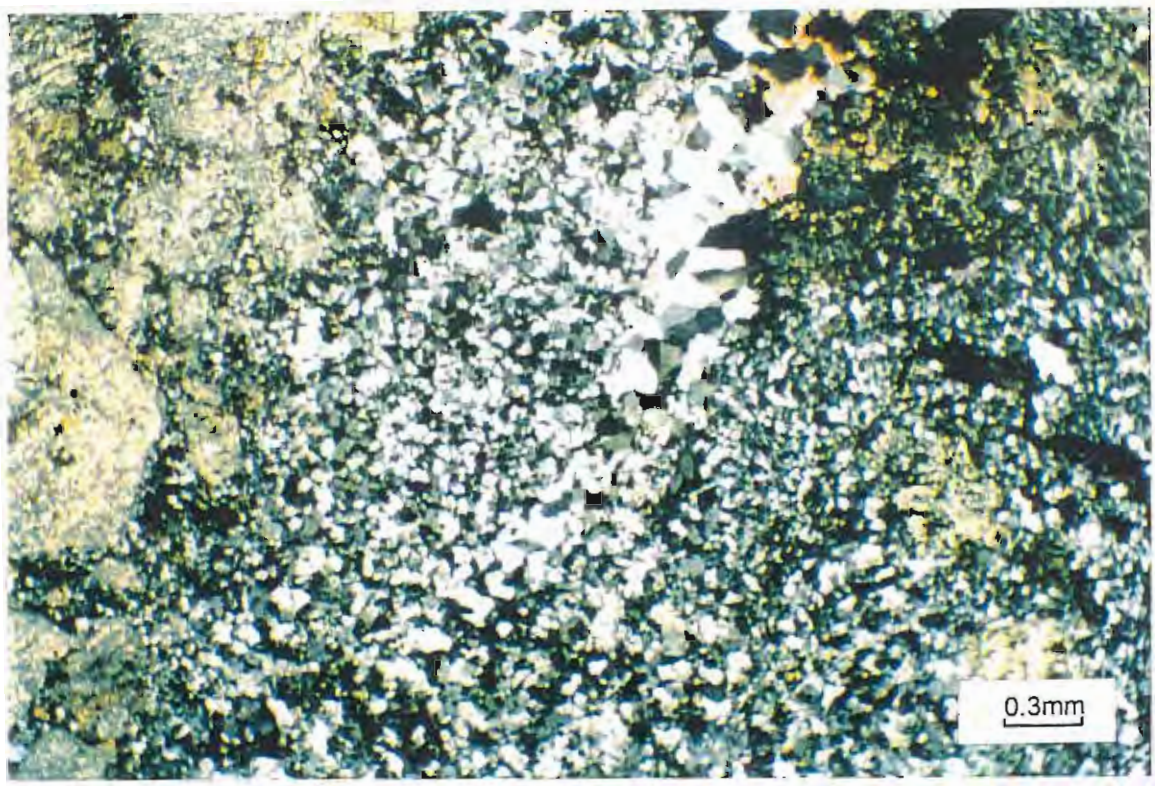
4.2.2.2.4 Pervasive Alteration

As with the disseminated alteration, pervasive alteration is widespread throughout much of the Waisoi porphyry copper/gold system. The pervasive alteration (Plate 4.18) occurs as zones of extremely fine-grained, intergrowths of anhedral to subhedral chlorite, magnetite, haematite, K-feldspar, quartz, sericite , biotite, calcite, albite, pyrite and epidote with only minor clays.

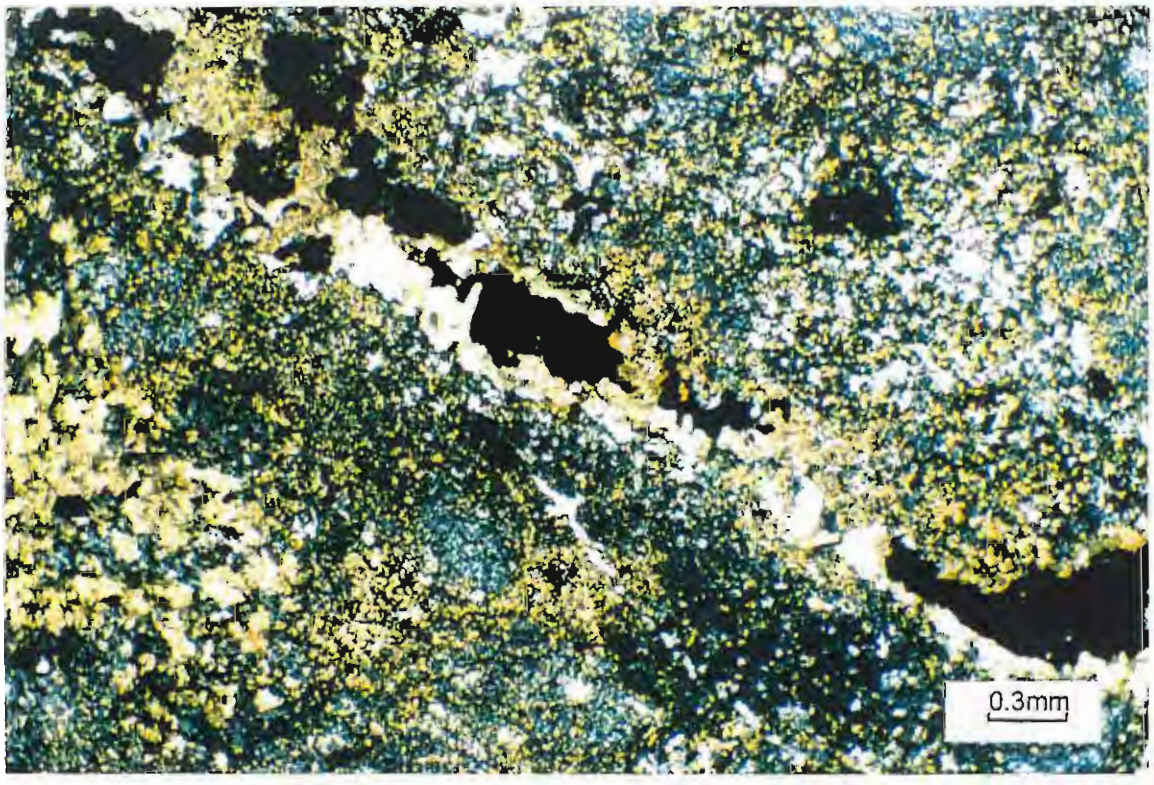
Generally, the most common pervasive alteration is that dominated by sericite and quartz, with minor, but variable, amounts of interstitial chlorite (Plate 4.19) and occasional disseminated pyrite +/- K-feldspar +/- magnetite +/- barite. The sericite and quartz occur as fine-grained intergrowths. The sericite is extremely fine-grained, pale cream to yellow to messy brown crystals occurring as dense meshes and mats in the groundmass of the volcanics, or as sericitised plagioclase phenocrysts. In areas of less intense alteration the sericite occurs as speckles throughout many plagioclase phenocrysts. Elsewhere sericite occurs as recrystallised, large patches with silica, sulphides and occasionally haematite/magnetite. Where the sericite and quartz are associated with barite, the sericite, quartz and barite occurs as intergrowths, commonly in small veinlets with pervasive quartz/sericite selvages. Fine-grained clay minerals are occasionally associated with sericite alteration.

Sericite also occurs as minor local, apparently fairly late-stage (prior to the late-stage, pervasive carbonate alteration event) sericite/pyrite alteration.

Although the sericite/quartz assemblage is the most common style of pervasive alteration in the Waisoi area, there is also an abundance of a pervasive alteration assemblage dominated by quartz, chlorite and fine-grained magnetite,

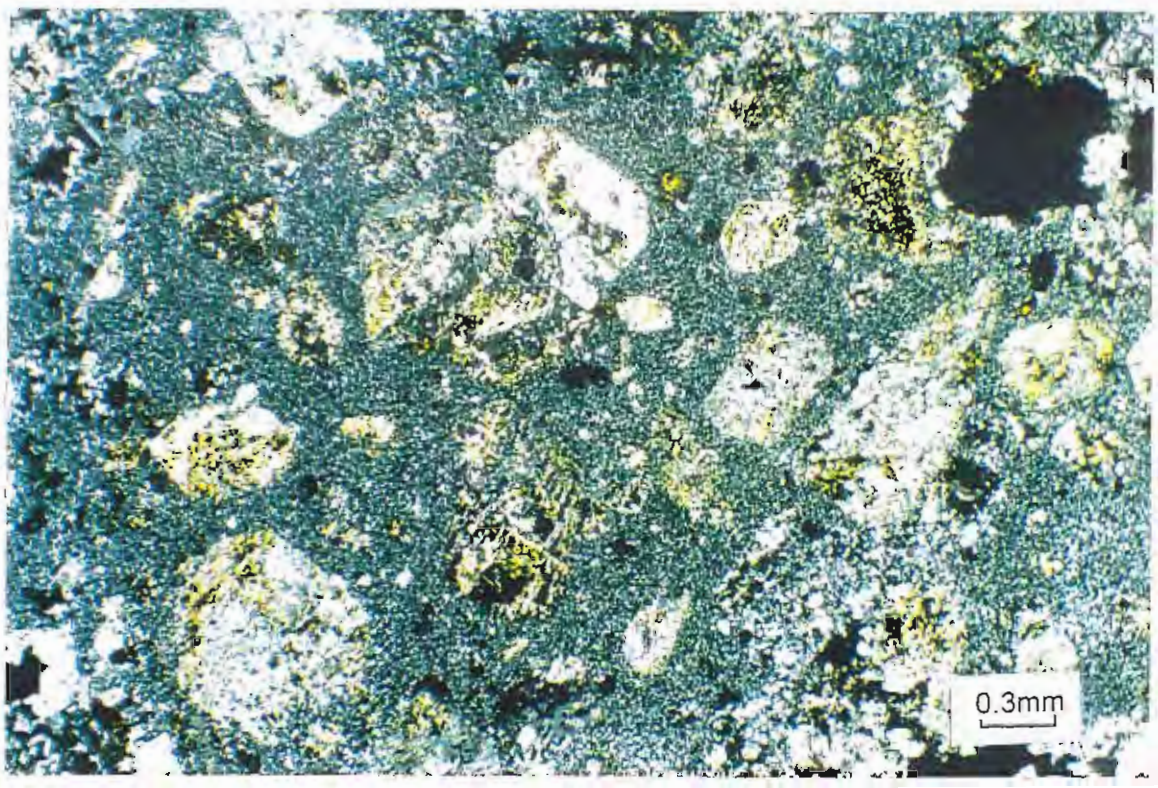


(a) Pervasive sericite alteration adjacent to a quartz vein with a quartz-albite outer zone (crossed nicols). WSD 217 - 200.90m

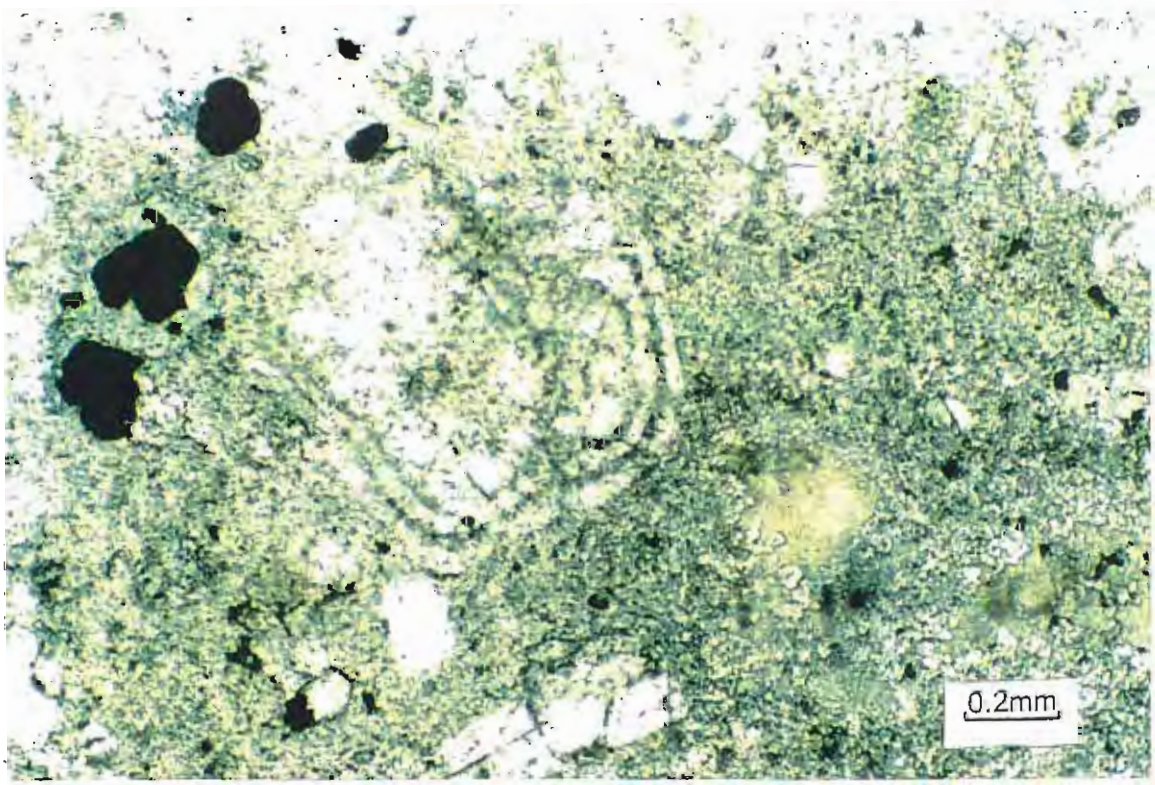


(b) Pervasive biotite alteration adjacent to a zoned quartz-biotite-sulphide vein in Wainimala Agglomerate (crossed nicols). WSD 81 - 193.00m

Plate 4.18 Pervasive alteration.



(a) Sericite-quartz-chlorite pervasive alteration of Namosi Andesite (crossed nicols). WSD 218 - 135.90m



(b) Sericite altered zoned plagioclase phenocryst (plain light) WSD 81 - 97.00m

Plate 4.19 Pervasive sericite alteration.

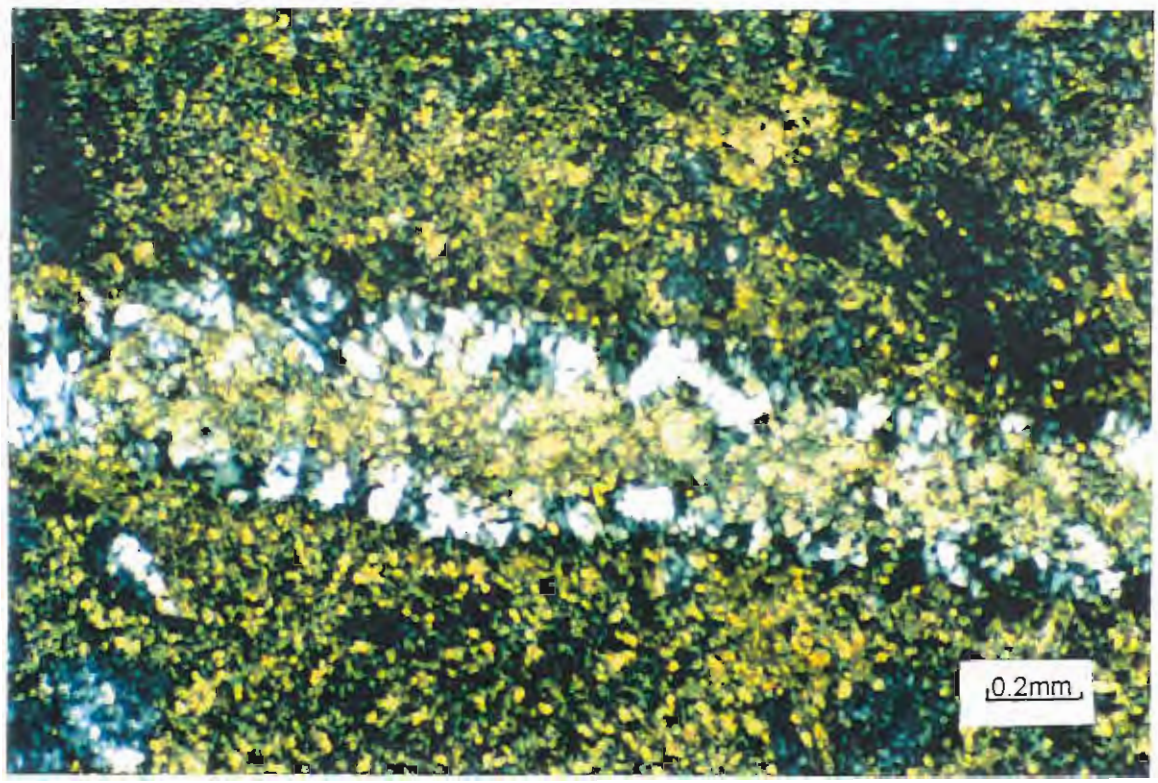
with variable amounts of biotite (Plate 4.18b). The chlorite occurs as very fine-grained, colourless to pale green (in places almost isotropic), bladed crystals. These occur as intergrowths with fine-grained quartz, and as small patches of crystal aggregates in the groundmass of the volcanics. In some zones the bladed chlorite occur with abundant, fine-grained, interstitial magnetite often with strongly pleochroic, brown biotite.

Where the alteration is closer to fluid pathways or intrusives, fine-grained, but variable, biotite (replacing mafics, sometimes as dense mats), is commonly intergrown with pale green chlorite and fine-grained, disseminated magnetite, and commonly occurs as concentrations on shear or fracture planes. Biotite also appears to define perlitic cracks in intensely altered, formerly glassy areas adjacent to higher temperature fluid pathways (Plate 4.20). Pale brown, strongly pleochroic biotite commonly associated with sulphides (particularly bornite, covellite and digenite), and occurring with minor stilpnomelane may indicate strong K-metasomatism (A. Crawford, pers.comm., 1992). Strongly pleochroic, brown biotite occurs occasionally with silica in high-strain zones.

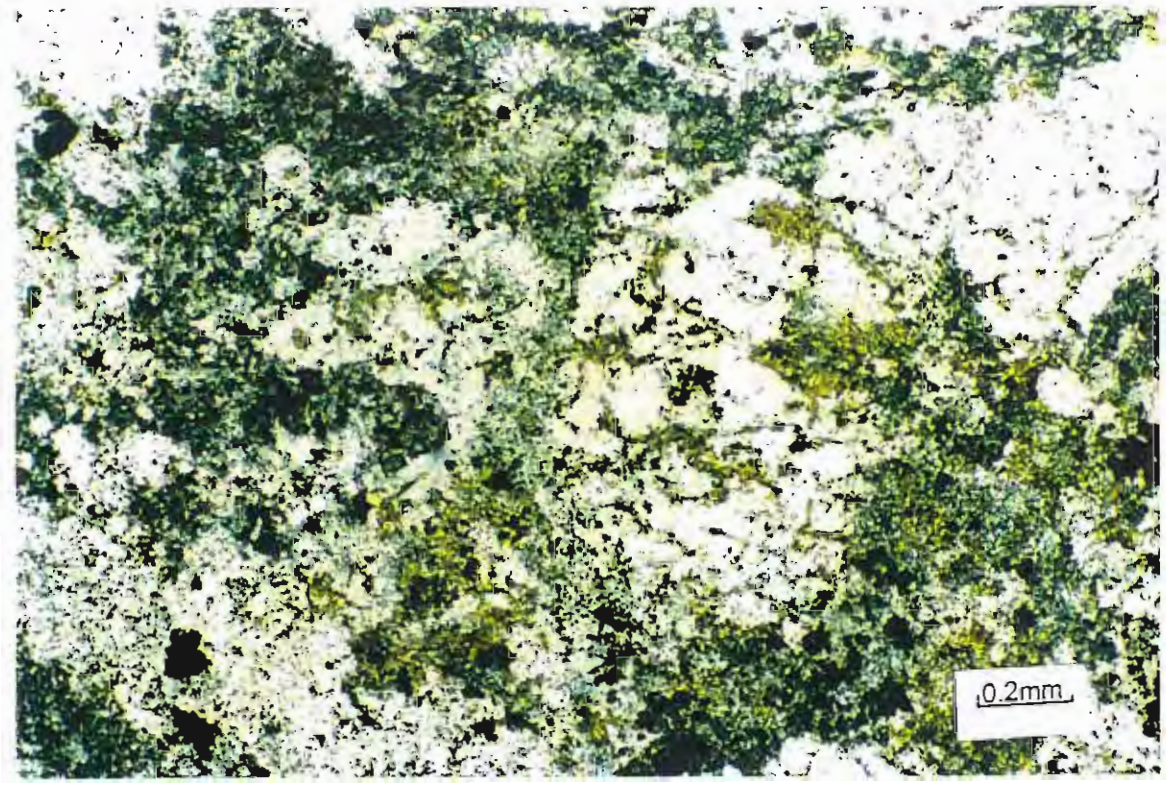
Several zones of pervasive silicification occur, particularly adjacent to areas where the porphyries intrude the lavas and volcaniclastics of the Namosi Andesite at Waisoi West. In these areas the quartz occurs as fine-grained, microcrystalline intergrowths with feldspar (now sericitised) throughout the groundmass of the volcanics (Plate 4.21).

The latest major pervasive alteration event introduced abundant carbonate into the Waisoi porphyry copper/gold deposit. This was mainly in the form of brownish-yellow, fine-grained calcite overprinting the groundmass of the volcanics throughout the stratigraphic section (Plate 4.22). This pervasive, fine-grained calcite was associated with coarse-grained calcite with quartz and fine-grained biotite (and possibly with siderite or ankerite) in veinlets and irregular patches. Calcite also rims some pyrite grains.

Another late-stage of pervasive alteration contains blebs (to 5mm across) of fine-grained laths of epidote, pyrite and calcite, surrounded by haloes of green

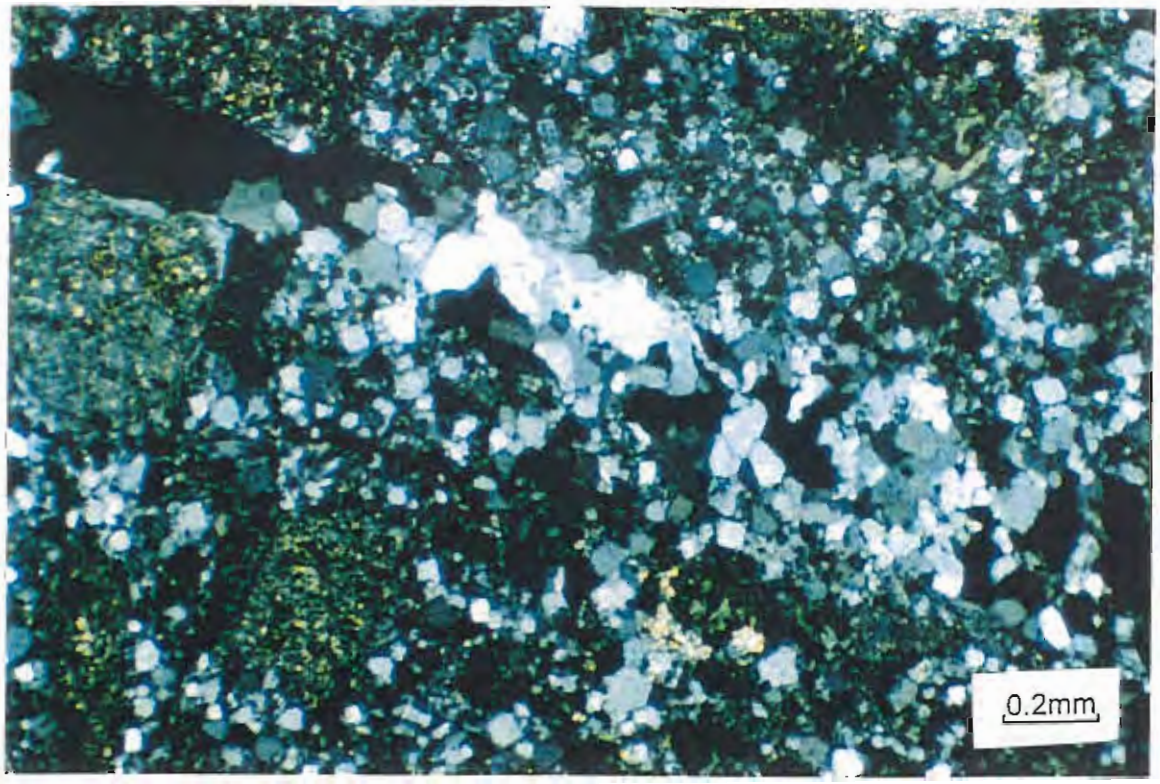


(a) Zoned quartz-biotite vein surrounded by pervasive biotite alteration (crossed nicols). WSD 217 - 265.50m

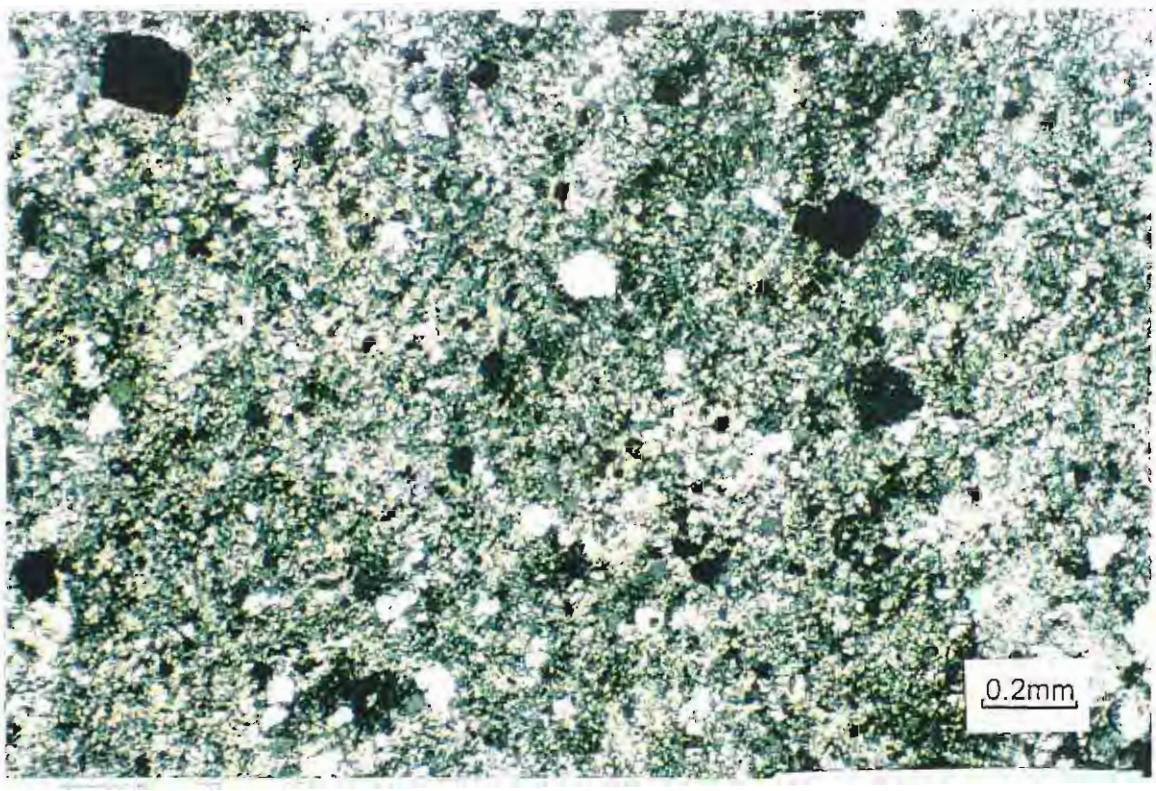


(b) Perlitic cracks defined by biotite in intensely altered, formerly glassy Wainimala Agglomerate (plain light). WSD 81 - 193.00m

Plate 4.20 Pervasive biotite alteration.

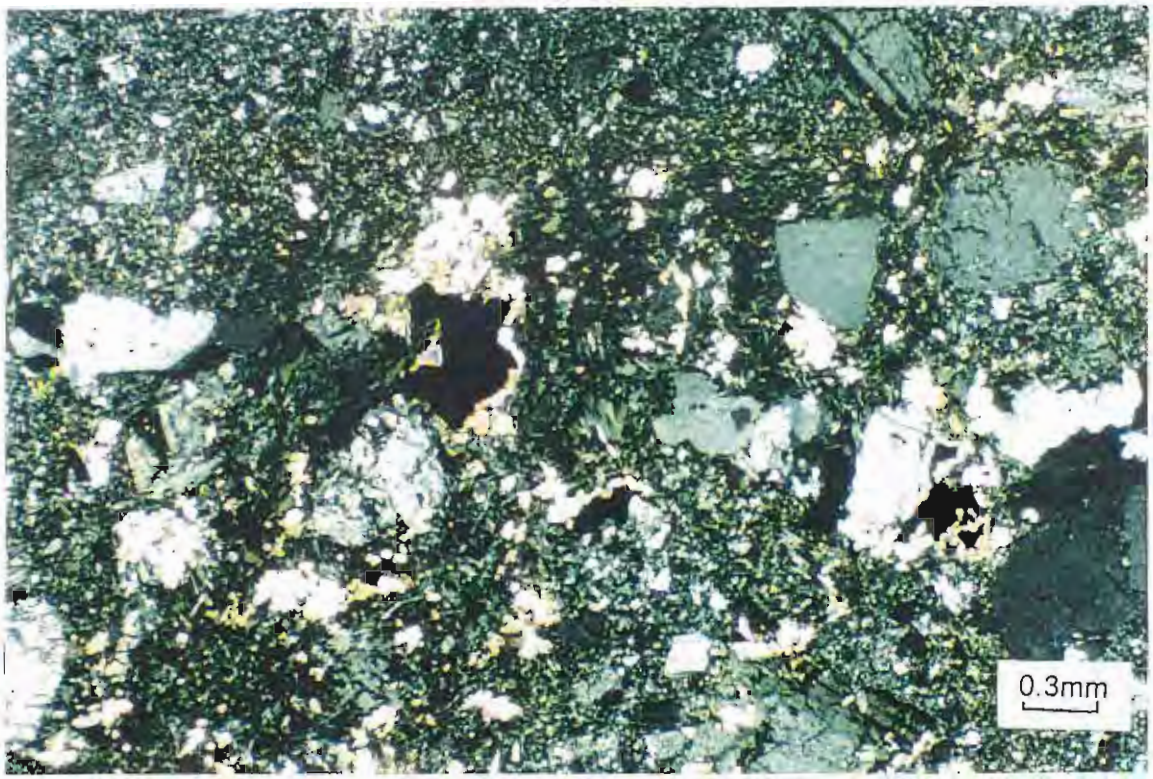


(a) Quartz-sulphide vein surrounded by fine-grained intergrowths of quartz and feldspar (crossed nicols) WSD 212 - 67.80m

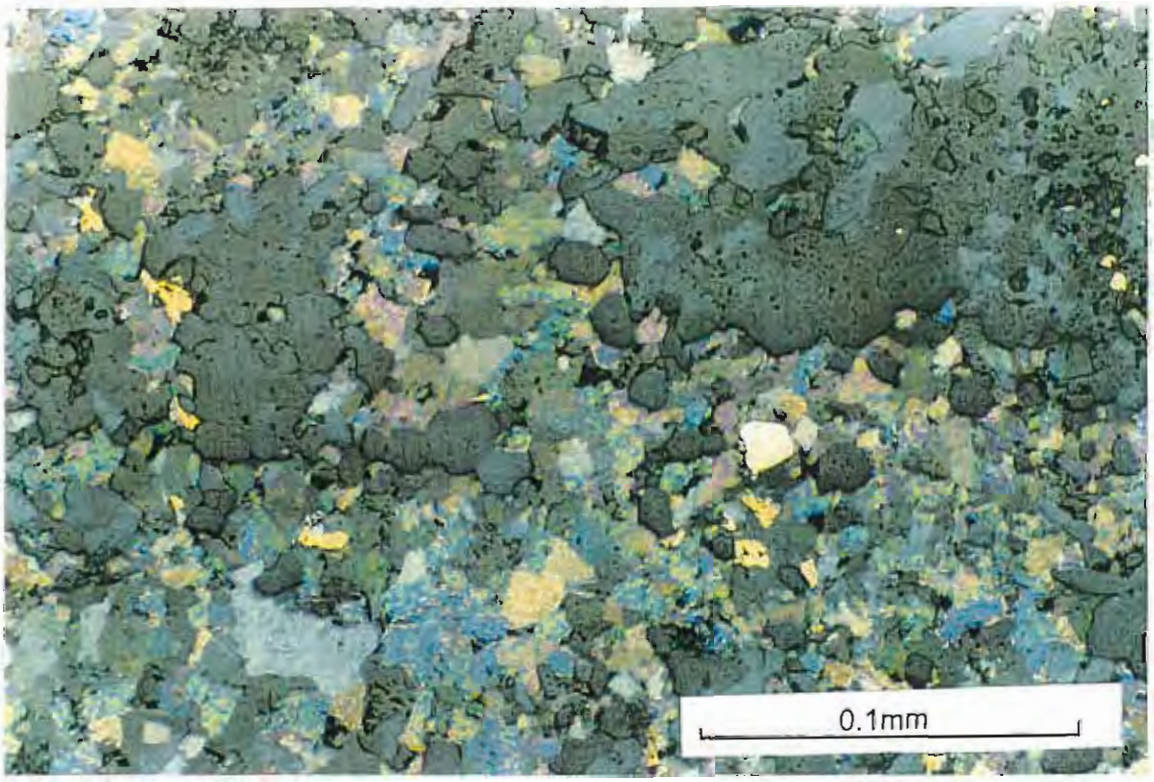


(b) Fine-grained intergrowths of quartz and feldspar with disseminated pyrite crystals in the Namosi Andesite (crossed nicols) WSD 217 - 70.00m

Plate 4.21 Pervasive silica alteration.



(a) A zone of pervasive calcite alteration with quartz and sulphides in the Namosi Andesite (crossed nicols). WSD 234 - 106.35m



(b) Micro-crystalline calcite pervasively altering the Namosi Andesite (crossed nicols). WSD 222 - 189.40m

Plate 4.22 Pervasive carbonate alteration.

chlorite. The epidote occurs as radiating crystal fans and blades in the calcite and anhedral pyrite aggregates.

Locally in the Wainimala Agglomerate volcanics the groundmass has undergone a local pervasive alteration consisting of intergrowths of quartz, albite, biotite, pink stilpnomelane, chlorite and magnetite (now haematite?). This alteration event appears to be an early event, during (or just after) the regional metamorphism.

4.3 MINERALISATION AND ALTERATION SUMMARY

The distribution, style, intensity and mineral composition of the Waisoi alteration and mineralisation is controlled by the local geology (Table 4.1). Fluids emanating from the porphyries alter the surrounding rocks depending upon the size of the porphyry, the nature of the surrounding rocks, and the availability of fluid pathways. The main controls on the distribution and type of alteration are the intruding porphyries, and the structures controlling these intrusives. Although the alteration at Waisoi is concentrically zoned around the intrusives, this zoning does not fit the idealised porphyry alteration zoning (Figure 4.5) proposed by Lowell and Guilbert (1970), Guilbert and Lowell (1974) and Guilbert (1986). The Waisoi alteration distribution is closer to that proposed (Hollister, 1978; Beane & Titley, 1981) in the "diorite model" (Figure 4.6), but there are still significant differences.

The alteration at Waisoi shows no recognisable phyllic zone (Lowell, 1979) due to the expanded stability fields of chlorite, biotite and magnetite. Ideal potassic alteration is within a zone of feldspar-destructive alteration, and is thus not as visible as in other porphyry systems. Also the low sulphur nature of the Waisoi system may reduce the amount of potassium in the fluids, due to the lower pH (W. Lacy, pers.comm., 1992).

However, the Waisoi mineralisation and alteration distribution, style and type conforms to the model proposed (Sillitoe, 1989; Cooke, 1994) for Western Pacific porphyry mineralisation (Figure 4.7). Biotite, with quartz, magnetite and minor K-feldspar are the main minerals associated with chalcopyrite and bornite veinlets (K-silicate alteration). Chlorite, calcite and epidote associated with pyrite extends out from the porphyry for several kilometres (propylitic alteration), while sericite, chlorite with some clay, calcite and epidote is an intermediate (between the K-feldspar and propylitic alteration) zone. Zones of sericite and quartz with pyrite (sericite alteration), and minor zones of alunite, kaolinite, pyrophyllite and pyrite (advanced argillic alteration), also occur.

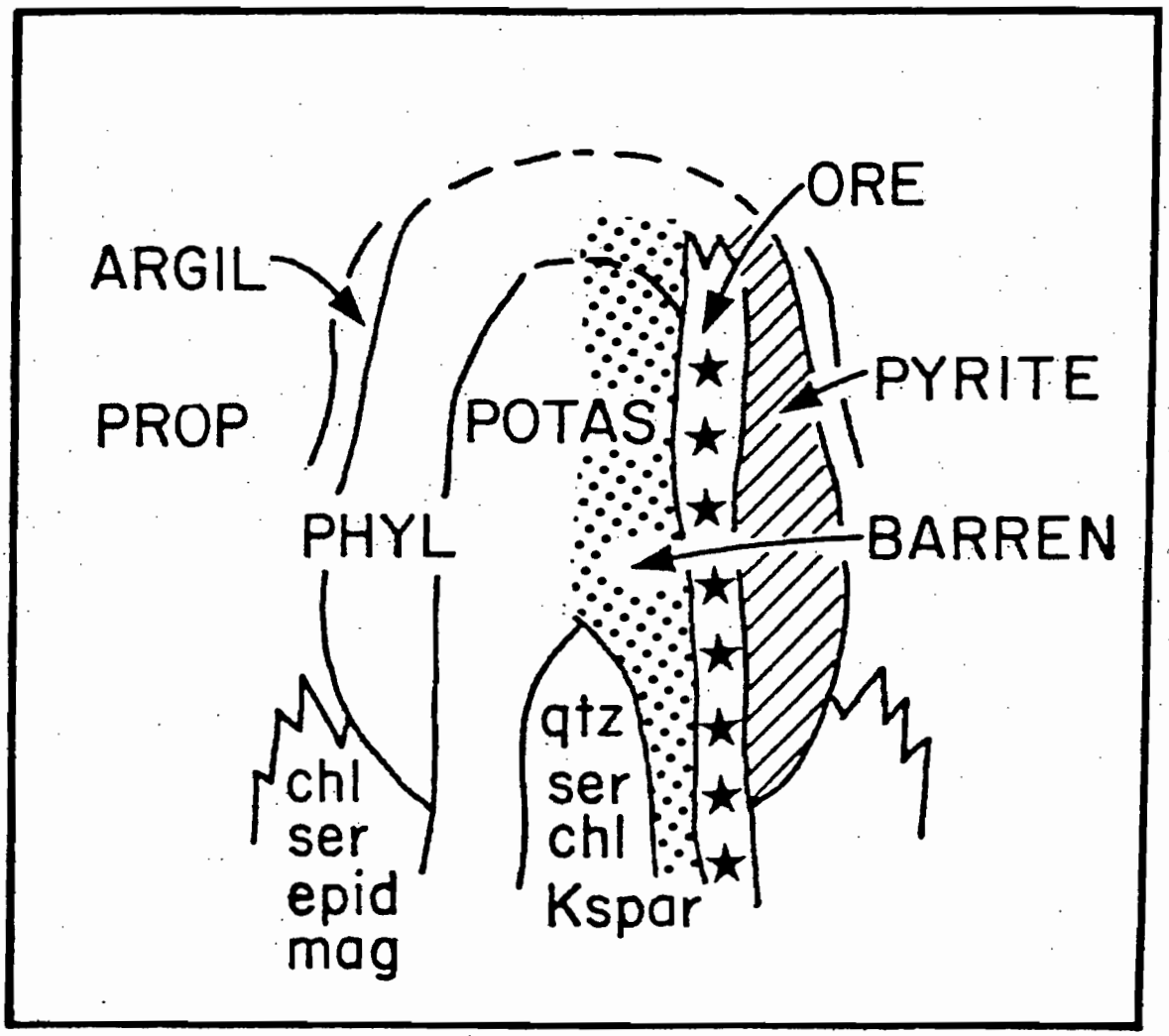
The main zone of mineralisation was concentrated at the contact of the Wainimala basement with the Namosi Andesite (Figures 3.4 to 3.9), where

Waisoi Alteration & Mineralisation Sequence.

ALTERATION CLASS	ALTERATION CODE	PORP	WAGL / BNAN	NAND
Outer Propyllitic	PRO 0	*No occurrence*	Chl+Silc+/- Epi +/- Calc +Py	Chl + Epi + Calc +Py
Inner Propyllitic	PRO 1	*No occurrence*	Chl(spots)+Qtz +Py +/-Cp	Qtz+Chl+Ser +/-Py
Outer Phyllic	PHY0	*No occurrence*	Mt+Bio +/-Bn>Cp>>Py	Chl+Ser+Mt +/-Cp
Inner Phyllic	PHY1	*No occurrence*	*No occurrence*	Chl+Bio+Ser+Mt +/-Cp+Bn
Potassic	POTS	Alb+Ser+Qtz+Cly +/- Bio +/- Cor +/- Py +/- Bn>>Cp	Kfs+/-Ser+/-Cly +/-Bn>>Cp>>Py	Kfs +/- Qtz +/-Bn>Cp
Argillic	ARGL	Cly+Ser+Chl +/-Bn>Cpy	*No occurrence*	Ser+Cly +/-Bn>>Cp
Silicic	SILC	Qvn+Silc +Cp	*No occurrence*	*No occurrence*
OVERPRINT				
LATE	CARB	Calc + Epi	Calc + Epi.	Calc + Epi
EARLY	QSTK	Silc + Qvn	Silc + Qvn	Silc + Qvn.

LIST OF ABBREVIATIONS			
Alb - Albite	Chl - Chlorite	Epi - Epidote	Qtz - Quartz Crystalline
Bio - Biotite	Cly - Clay	Kfs - Potassium Feldspar	Qvn - Quartz Vein
Bn - bornite	Cor - Corundum	Mt - Magnetite	Ser - Sericite
Calc - Calcite	Cp - Chalopyrite	Py - Pyrite	Silc -Polycrystalline to cryptocrystalline
PORP - Porphyry Intrusives	WAGL - Wainamala Agglomerate	BNAN - Basal Namosi Conglomerate	NAND - Namosi Andesite

Table 4.1 Variations in alteration/mineralisation with rock type of Waisoi.



KEY

chl = chlorite
ser = sericite
epid = epidote
mag = magnetite
qtz = quartz
kspar = K feldspar

Figure 4.5 Lowell & Guilbert classical porphyry alteration model. (after Beane & Titley, 1981).
Vertical cross section showing zonal relations among hydrothermal mineral assemblages in a "typical" porphyry copper deposit (after Lowell and Guilbert, 1970, fig.3). Left side = silicate assemblages: potas(sic), phyl(lic) argil(lic), prop(ylitic). Right side = sulfide zones: pyrite shell, ore shell, barren core.

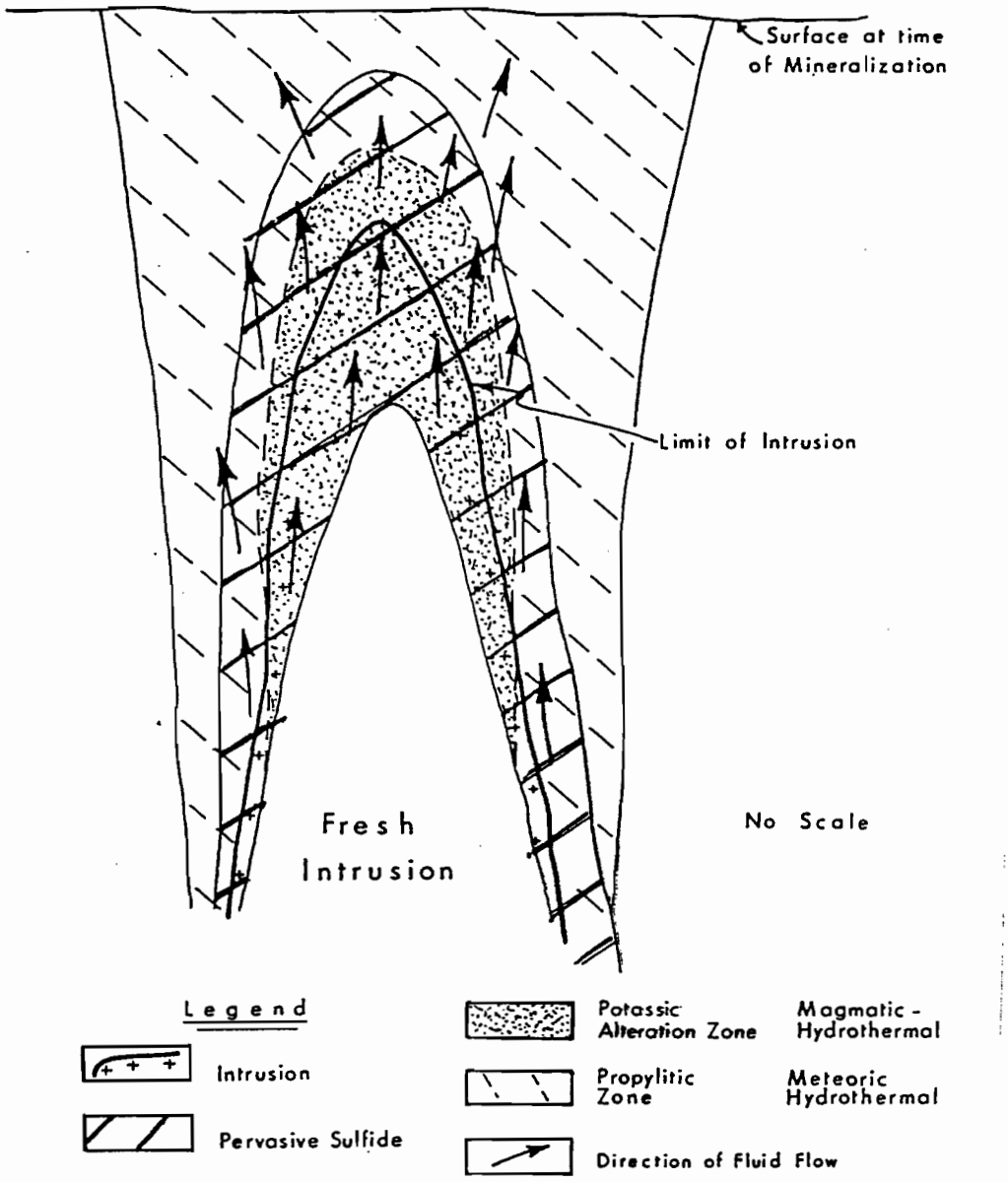


Figure 4.6

Diorite model. Flow direction during simultaneous action by the magmatic-hydrothermal and meteoric-hydrothermal systems is indicated by arrows. Activity by the latter after cessation of magmatic-hydrothermal fluid flow may result in substantial destruction of the previously formed potassic zone (as at Copper Mountain-Ingerbelle, British Columbia).

(After Hollister 1978).

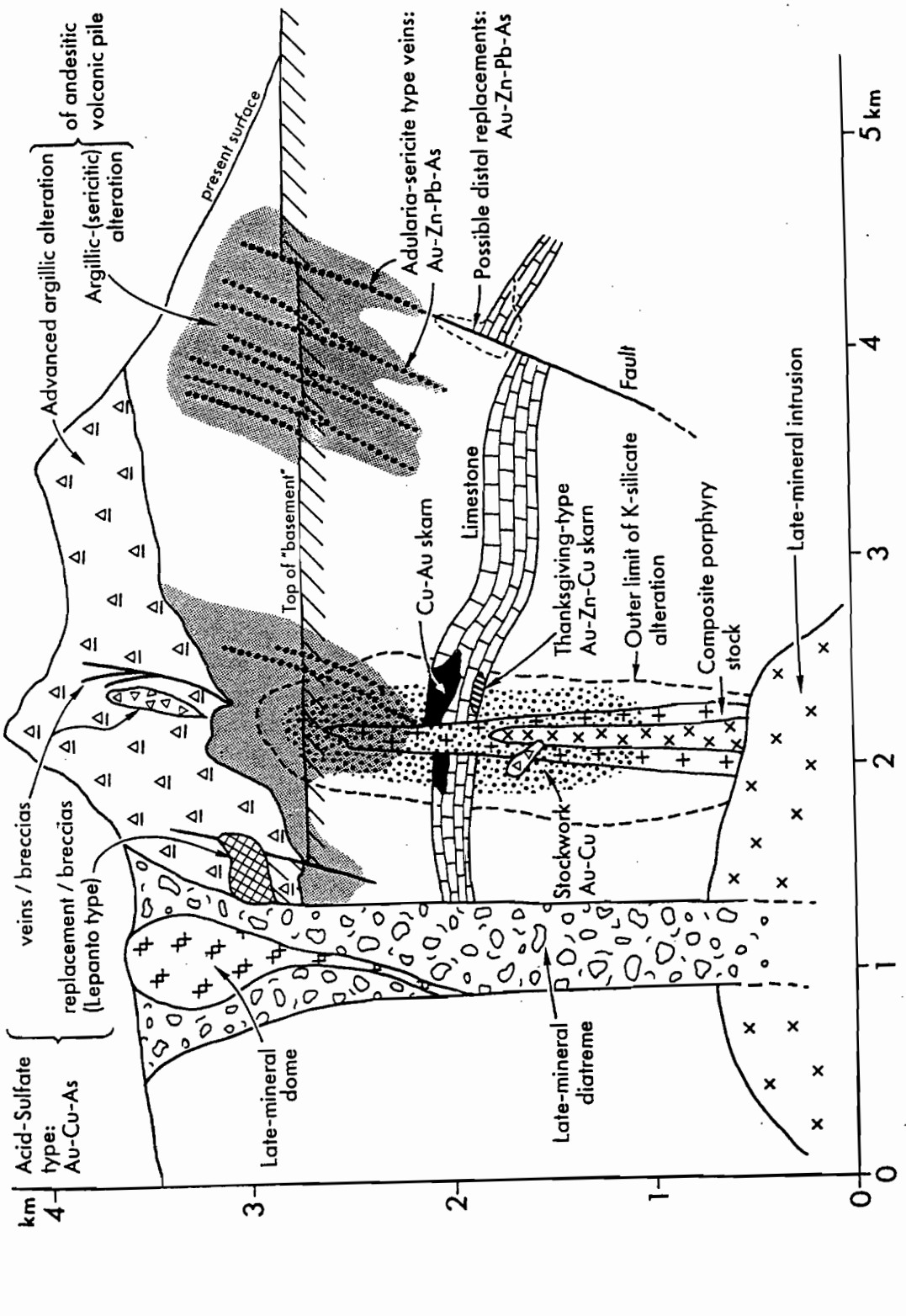


Figure 4.7 Styles of mineralisation in a typical western Pacific porphyry copper system. A single system does not necessarily contain all mineralisation styles depicted (after Sillitoe, 1989; Cooke, 1994).

strong fracturing has been observed. This zone represented a physio-chemical change suitable for mineral deposition. The intrusion of the dacitic porphyries shattered the glassy Wainimala lavas allowing fluids from the intrusives to flow through and come into contact with the andesitic lavas. The resultant pressure drop and chemical interaction led to the formation of the porphyry mineralisation, particularly in the Wainimala Agglomerate. Similar properties of the Basal Namosi Conglomerate also led to significant mineralisation in this conglomeratic unit where it came into contact with the fluids from the porphyries.

The earlier, weakly mineralised, but highly fractured P5 intrusive event, and later intersecting northwest and northeast structural events (all of which are evident throughout the Waisoi area, but are particularly prominent in the vicinity of the Waisoi West, Waisoi East and Waisoi North mineralised zones), caused a concentration of mineralising fluids, which resulted in a concentration of mineralisation in the three deposits. The remainder of the area, with weaker expressions of the northwest- and northeast-trending structures, contains anomalous levels of copper, and to a lesser extent, gold and molybdenum.

4.4 PARAGENESIS

4.4.1 General

Although the style, character and intensity of the alteration and mineralisation varies throughout the Waisoi deposits, the study of many thin sections from all parts of the deposits has led to the identification of a paragenesis for the deposit (Figure 4.8). This is divided into pre-porphyry and porphyry-related events.

4.4.2 Pre-Porphyry Alteration

The pre-porphyry alteration consists of an early albitisation event overprinted by a regional burial metamorphic event. These events have only been observed in some rocks from the Wainimala basement and are:

	Pervasive	Disseminated	Vein
Regional greenschist facies burial metamorphism	albite+biotite+ chlorite+actinolite+ /-quartz+/-epidote	magnetite+/- pyrite	chlorite+actinolite+/ -biotite+/-quartz
Albitisation	albite+quartz		albite+quartz

Table 4.2 Pre-porphyry alteration minerals

Almost all Wainimala Agglomerate samples show a pervasive alteration assemblage of albite-biotite-chlorite-actinolite+/-quartz+/-magnetite in the groundmass (Plates 4.9 & 4.10). The albite occurs as alteration of the plagioclase phenocrysts. However abundant albite also occurs intergrown with fine-grained chlorite, biotite, anhedral magnetite, more coarse quartz, and possibly some epidote, throughout the groundmass. Minor disseminated pyrite also occurs scattered throughout the groundmass. This assemblage reflects regional burial metamorphism to greenschist facies. Although recognised throughout the Wainimala basement rocks, the intensity of the alteration and the mineral assemblage does tend to vary. Where the Wainimala Agglomerate is particularly fractured veinlets of chlorite and actinolite +/- biotite are common, and tend to be cross-cut by quartz veinlets. Magnetite tends to occur as tiny, disseminated irregular crystals, particularly in areas of abundant formerly mafic minerals.

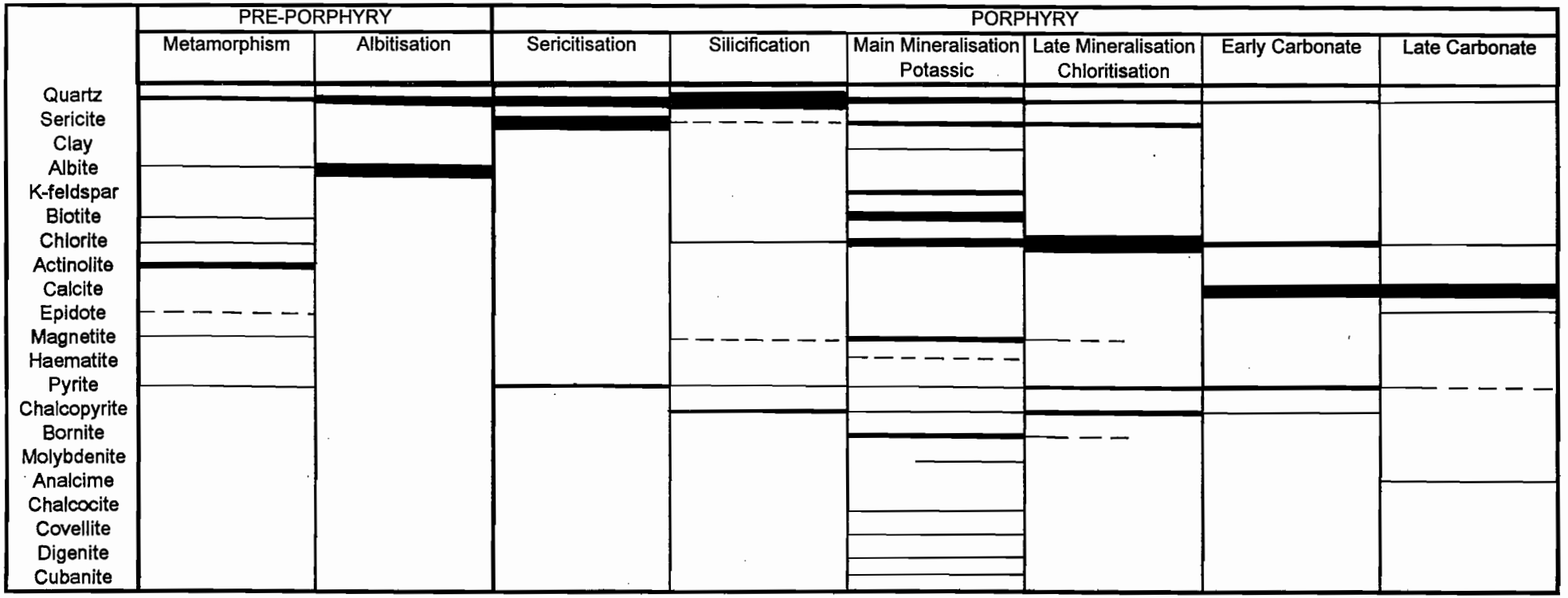


Figure 4.8 Generalised paragenetic sequence for the alteration events at Waisoi. The thickness of the lines represents the relative abundance of each mineral at each stage. Gold is associated with copper sulphides.

A similar assemblage has been recognised in some samples taken from the Basal Namosi Conglomerate, but these are all from the basal parts of the conglomerate unit and represent included fragments of the regionally metamorphosed basement.

The regional burial metamorphic assemblage appears to be associated with, or overprint, an albitisation event. Some samples of Wainimala basement rocks contain plagioclase phenocrysts and a groundmass that have undergone weak to intense albitisation by an assemblage dominated by albite, but with variable amounts of quartz. In some cases the intensity of the albitisation is such that all zoning within the plagioclase phenocrysts is destroyed, yet elsewhere the phenocrysts are rimmed by albite. Albitisation is the earliest recognisable event and is often destroyed, or at least made difficult to recognise, by later events, particularly the regional metamorphism and intense sericite alteration.

In the Wainimala Agglomerate, rare thin veinlets containing fine-grained quartz with very fine-grained albite maybe associated with the early regional metamorphic event.

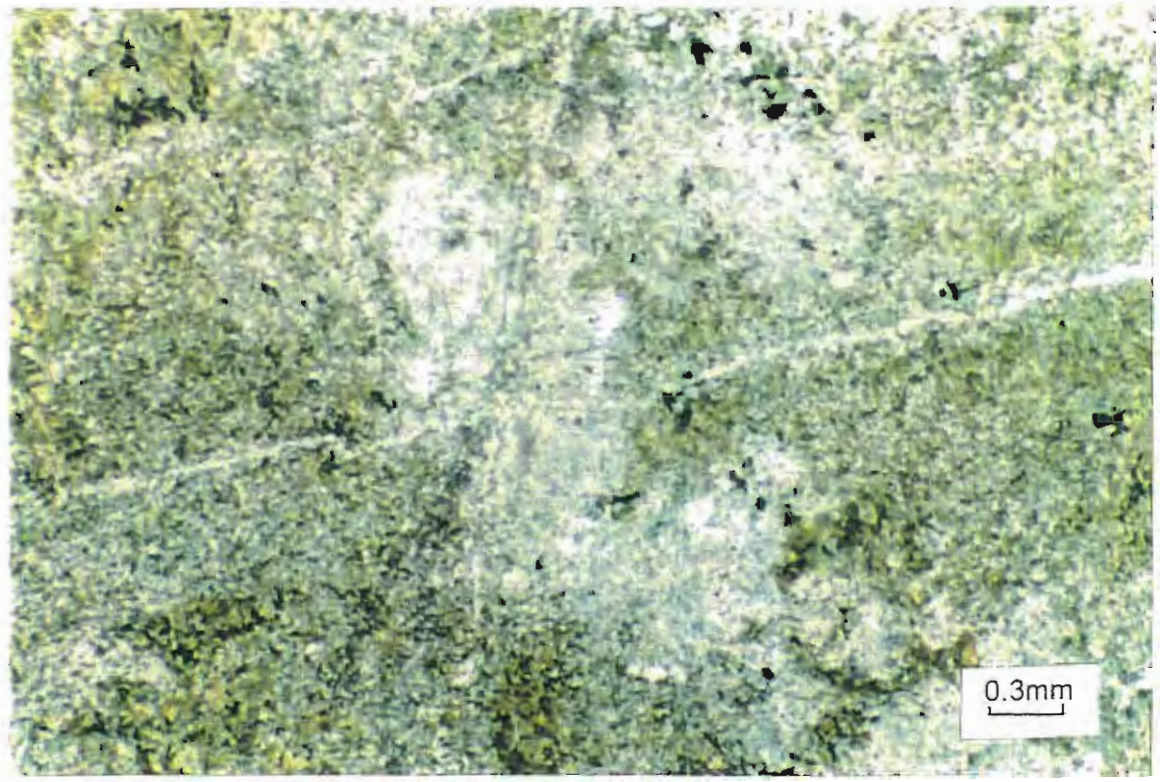
4.4.3 Porphyry Alteration

Although the most diagnostic means of determining the paragenesis of the porphyry deposits is by studying the cross-cutting relationships of vein mineralisation (Plates 4.23 and 4.24) and the related alteration, at Waisoi the disseminated and pervasive alteration also helps to determine the paragenetic sequence of alteration and mineralisation.

The evaluation of the mineralisation and alteration observed in polished thin section shows that after the extrusion of the Namosi Andesite lavas and volcaniclastics the rocks in the vicinity of the Waisoi dacitic quartz diorites underwent a series of hydrothermal events (Table 4.3).

4.4.3.1 Sericite Alteration

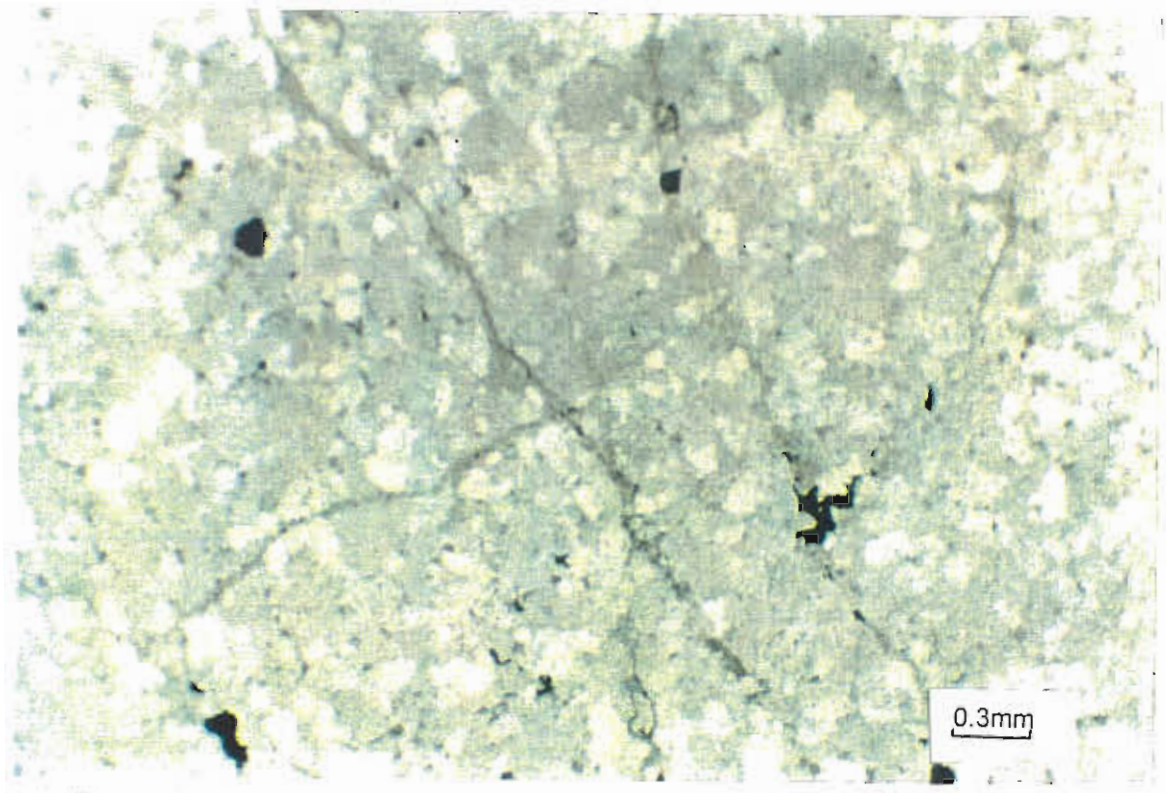
The earliest event that generally affects the Namosi Andesite and Basal Namosi Conglomerate, but overprints the regional burial metamorphism of the Wainimala basement rocks is widespread, patchy, pervasive sericitisation. This



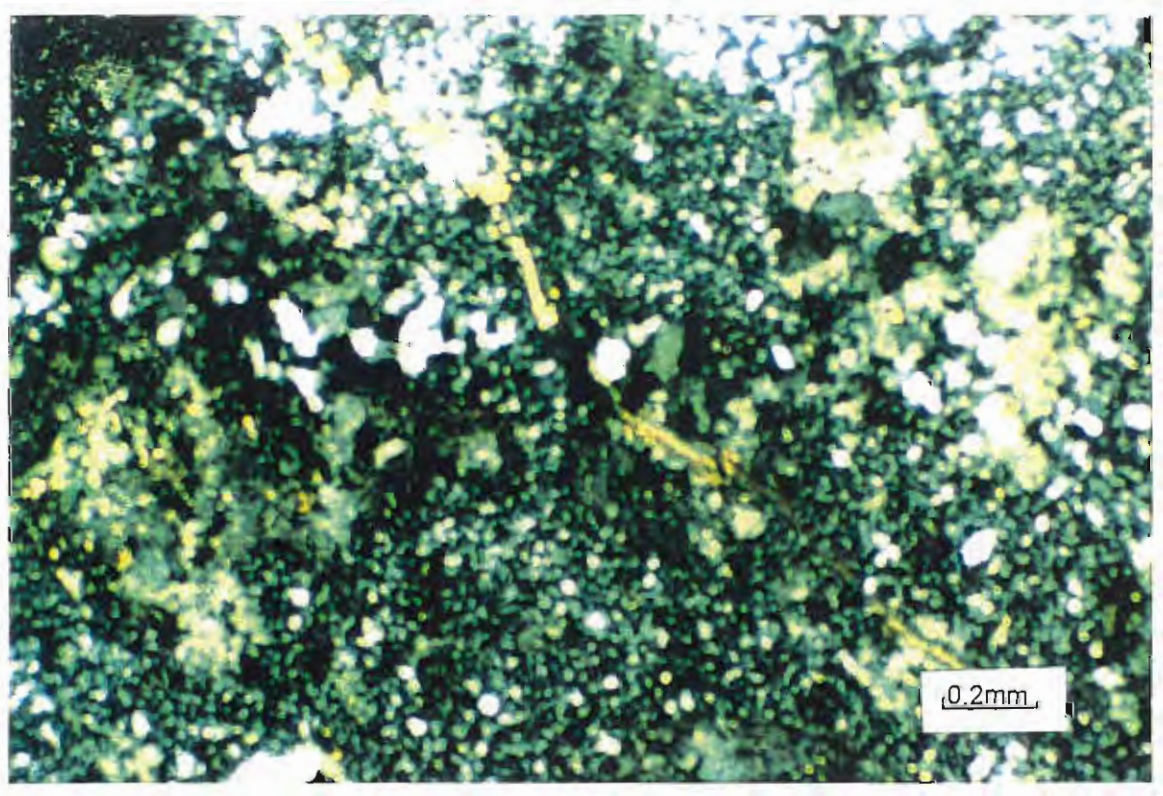
(a) Quartz veinlet cut by sericite veinlet (plain light). WSD 212 - 195.80m

(b) Biotite-quartz veinlet and quartz-albite veinlet cut by quartz-sulphide veinlets (plain light). WSD 212 - 235.00m

Plate 4.23 Complex cross-cutting vein relationships.



(a) Micro-crystalline quartz vein cut by chlorite-sericite-pyrite fracture-fill (plain light). WSD 212 - 80.10m



(b) Calcite veinlet cut by quartz vein (crossed nicols). WSD 212 - 36.95m

Plate 4.24 Vein relationships.

	Pervasive	Disseminated	Vein
sericitisation	sericite+quartz	pyrite	quartz+sericite+/-pyrite
silicification	quartz+chlorite	pyrite+/-chalcopyrite	quartz+chlorite+/-pyrite+/-chalcopyrite
main mineralisation (potassic)	quartz+biotite+/-K-feldspar+/-chlorite+/-clay+/-sericite	chalcopyrite+magnetite+/-pyrite	quartz+ bornite+magnetite+biotite+chalcopyrite+/-digenite+/-cubanite
late main mineralisation (chloritic - propylitic)	chlorite+sericite+/-quartz	pyrite+chalcopyrite	Quartz+chlorite+chalcopyrite+/-pyrite
early carbonate	calcite+quartz+/-chlorite	pyrite+chalcopyrite	quartz+calcite+pyrite+chalcopyrite
late carbonate	calcite+/-chlorite+/-epidote+/-quartz	pyrite	calcite+/-quartz+/-pyrite+/-analcime

Table 4.3 Porphyry related alteration minerals

is characterised by abundant sericite, with lesser amounts of quartz and pyrite. The sericite overprints and replaces:

- the albitised and non-albitised feldspars in the Wainimala lavas,
- the devitrified and recrystallised quartz/feldspar groundmass of the lavas and volcaniclastics, and
- the plagioclase phenocrysts in the Namosi Andesite lavas.

The quartz occurs as fine-grained intergrowths with the sericite and as fine-grained, quartz-rich veinlets. Fine-grained idiomorphic pyrite occurs scattered in variable quantities through the quartz-sericite groundmass, and in minor amounts in quartz-sericite veinlets. Veining (0.1 to 2 mm in width) associated with the sericitisation have polycrystalline quartz cores grading outwards to quartz-sericite+/-pyrite edges.

The sericite alteration is controlled by fluid pathways, particularly in the Wainimala Agglomerate and the Basal Namosi Conglomerate, where the effect of the alteration can be observed up to 40 cm (although commonly extending only 5 to 10 cm) from veinlets and fractures. Portions of the Wainimala Agglomerate appear to be un-affected by the sericitisation, probably due to a lack of fracturing. In the Namosi Andesite the sericite alteration is more widespread and pervasive, but weaker. This probably relates to the disperse nature of fluid movement through the lavas and volcaniclastics units.

4.4.3.2 Silica Alteration

The sericitic alteration is overprinted by a silicification event consisting of both pervasive silica and quartz veining. Silicification is characterised dominantly by quartz with significantly lesser but variable amounts of chlorite and pyrite. The fine-grained pervasive silica occurs as patches of clear, polycrystalline quartz (probably after sericite) intergrown with fine-grained chlorite and containing tiny, irregular pyrite euhedra. In zones of intense alteration the silica has replaced former plagioclase phenocrysts by almost isotropic, extremely fine-grained quartz set in a groundmass of totally recrystallised quartz-chlorite with equi-dimensional tiny magnetite grains. This pervasive alteration surrounds thin (0.2 to 40 mm wide but commonly less than 10 mm wide) quartz+/-chlorite+/-pyrite+/-

chalcopyrite veins and veinlets. In areas of intense silicification, such as the Waisoi West stockwork ridge, the veinlets contain fine- to coarse-grained, clear to white, polycrystalline quartz, associated with subhedral pyrite grains and minor chlorite. Minor amounts of chalcopyrite occur with, and replacing, pyrite in some quartz veins from this stage, particularly towards the intrusive contacts or major fluid pathways.

As for the sericitisation, the silicification is controlled by fluid flow along discreet pathways (structures and fractures) in the Wainimala Agglomerate and the Basal Namosi Conglomerate, but by dispersion through the Namosi Andesite. This has led to widespread diffuse zones of weaker silicification in the Namosi Andesite, and patchy zones of intense silicification in unaltered rocks in the lower rock units.

Silicification also appears to have occurred within the larger porphyry bodies where abundant quartz+/-K-feldspar+/-sericite veins occur as intense stockworks in pervasively silicified porphyry (up to 90% silica). The timing of this silicification is uncertain.

4.4.3.3 Potassic Alteration

The general silicification event is followed and overprinted by the main mineralising event which is associated with the introduction of biotite and K-feldspar (potassic) alteration. Thin (0.02 to 4 mm) veins and veinlets of quartz-biotite-bornite-magnetite with lesser amounts of chlorite-chalcopyrite and minor chalcocite+/-covellite+/-digenite+/-cubanite are surrounded by alteration envelopes of pervasive quartz-biotite, grading outwards to K-feldspar with chlorite and minor sericite-clay zones. Some of the veins are well zoned from a bornite-chalcopyrite centre surrounded by coarse, polycrystalline quartz zone, to an outer zone of fine-grained quartz grading out into the pervasive K-silicate alteration. In a few areas it appears as though the biotite has regressed to chlorite. Throughout the pervasive potassic alteration, are scattered irregular, fine-grained chalcopyrite and magnetite, with minor pyrite in the outer zones. Several zones of weak quartz-chlorite-K-feldspar alteration with fine-grained haematite are believed to be associated with this main mineralisation event.

Alteration associated with the main mineralising event is controlled by fracture-controlled fluid pathways and is mostly associated with the Wainimala Agglomerate and Basal Namosi Conglomerate. The main occurrence of biotite-rich alteration in the Namosi Andesite is in the shattered zones in the vicinity of the porphyry contacts, particularly in Waisoi West. Generally the pervasive potassic alteration extends only 1 to 5 cm from the vein boundaries, but in the Waisoi North area biotite-quartz-K-feldspar alteration extends 50 to 100 cm out from fracture controlled fluid pathways in the P5 porphyry dykes. In general, bornite, biotite and magnetite tend to increase in the country rock as distance to the intrusives decreased. Pink K feldspar also is more abundant in the country rocks close to the intrusives, but there is a sharp limit, unlike the more gradual boundary shown by the bornite-biotite-magnetite distribution.

4.3.3.4 Chlorite Alteration

The main mineralising episode is followed by a later (probably associated waning stage) mineralising event dominated by quartz-chlorite veining with significant chalcopyrite and minor pyrite. These 0.1 to 20 mm veins are surrounded by an envelope of disseminated chlorite-sericite and lesser amounts of silica. Within the pervasively altered envelope there are often abundant, disseminated, fine-grained chalcopyrite and pyrite with occasional grains of bornite and magnetite.

The envelope of disseminated mineralisation generally extends only up to 20 cm from the vein boundaries (less in the Wainimala Agglomerate) but can extend over 70 cm at some locations in the Namosi Andesite.

4.3.3.5 Carbonate Alteration

The mineralising events are followed by two (probably related) phases of carbonate dominated alteration. The first carbonate-rich alteration phase consists of 0.5 to 15 mm quartz-calcite veins, with variable amounts of chalcopyrite and pyrite, surrounded by a pervasive calcite-quartz alteration. The veins are dominated by polycrystalline quartz grains, with fine-grained anhedral chalcopyrite intergrown and surrounded with pyrite, surrounded by irregular calcite grains. Outwards from the veins the rock is dominated by interstitial

intergrowths of fine-grained calcite with irregular quartz grains and very fine-grained chlorite. Beyond 5 to 10 cm from the veins the carbonate-dominated alteration becomes patchy with small zones of pervasive calcite-chlorite+/-quartz alteration. Throughout the zone of calcite-dominated alteration there is fine-grained, disseminated chalcopyrite and pyrite.

The second carbonate-dominated phase of alteration consists of 0.3 to 15 mm wide veins of calcite with minor amounts of quartz-pyrite-analcime, surrounded by a zone of pervasive calcite alteration. The pervasive calcite alteration is dominated by fine-grained calcite (some rninor rhombs) intergrown into a messy aggregate with lesser amounts of fine-grained chlorite and minor epidote and quartz. In zones of intense carbonate alteration, calcite forms rims around resorbed, reacted pyrite grains. Zones of dominant epidote with subordinate calcite also occur adjacent to epidote-rich veins.

4.3.4 Paragenesis Summary

In simple terms the rocks in the vicinity of the Waisoi porphyry copper/gold deposits have undergone the following alteration events:

	Stage	Sub-stage	Minerals
Pre Porphyry	regional	albitisation	albite,quartz
		metamorphism	albite-biotite-chlorite-actinolite+/- quartz-epidote-magnetite- pyrite
Porphyry	sericitisation		sericite-quartz+/-pyrite
	silicification		quartz-chlorite+/-pyrite-chalcopyrite
	mineralisation	main	quartz-biotite-magnetite-bornite-chalcopyrite+/-K-feldspar-chlorite-clay-sericite-pyrite-chalcocite-covellite-digenite-cubanite
		late	quartz-chlorite-sericite-chalcopyrite+/-pyrite
	carbonate	early	calcite-quartz+/-chlorite-pyrite-chalcopyrite
		late	calcite+/-quartz-chlorite-pyrite-epidote-analcime

Table 4.4 Waisoi Alteration Sequence

This is shown diagrammatically in Figure 4.8. The albitisation and regional metamorphic events occurred prior to the deposition of the Basal Namosi Conglomerate and affect only the Wainimala Agglomerate. The albitisation appears to be the earliest event, but it may have been associated with the early stages of regional metamorphism.

During the later stages of the deposition of the Namosi Andesite, all the rocks were affected by hydrothermal alteration related to the intrusion of the dacitic quartz diorites at Waisoi. This consisted of early sericitisation (probably post-devitrification and recrystallisation of the groundmass of the volcanics), followed by silicification, and then mineralisation (with potassic alteration followed by chloritisation or propylitic alteration). The final stages of mineralisation merged into a carbonate event, prior to the cessation of significant alteration.

Both quartz and sulphides are common to all phases of hydrothermal alteration noted at Waisoi. This includes the recrystallisation of the groundmass, the early sericitisation event, the quartz-rich veining and silicification, and the late carbonate-rich event. The sulphides, however, vary from an early pyrite phase, changing to a base metal dominant phase, and a final pyrite-rich phase. Pyrite has occurred in all stages of the paragenetic sequence but also occurs in a wide range of locations such as; within primary rock-forming crystals (such as plagioclase phenocrysts), internal blebs in alteration minerals, within the altered groundmass, along fragment boundaries, interstitial areas, and finally in veins.

Copper was first precipitated (in minor quantities) as chalcopyrite in the silicification stage of porphyry evolution. As the mineralising system evolved to fluids causing the potassic alteration of the host rocks, precipitation of copper increased, and changed from dominantly chalcopyrite to dominantly bornite. The evolution of the porphyry system to a chloritic alteration stage was accompanied by copper precipitation changing to chalcopyrite dominated, which continued (in decreasing amounts) through to the early stages of carbonate alteration.

Gold values are very low throughout the Waisoi mineralisation (average 0.14ppm, with the only higher grades of 1.2ppm in the structurally remobilised massive sulphides), but are associated with the copper mineralisation

(particularly the bornite). Most of the gold was deposited during the potassic alteration stage of the evolution of the Waisoi porphyry system.

PART 5

WAISOI GEOCHEMISTRY

5.1 FLUID INCLUSIONS

5.1.1 General

During the mineralogical and alteration study of thin sections, samples suitable for fluid inclusion evaluation were selected and doubly polished thin sections were prepared. The 35 samples were selected to represent as many of the paragenetic stages associated with the porphyry mineralisation as possible. On completion of the preparation, the samples were re-examined and several were found to be unsuitable for fluid inclusion studies and were discarded. From chips of the suitable selected samples temperatures of liquid-vapour homogenisation, daughter mineral dissolution, freezing point depression and first melting were measured. The inclusions were examined and described prior to the freezing and heating evaluations.

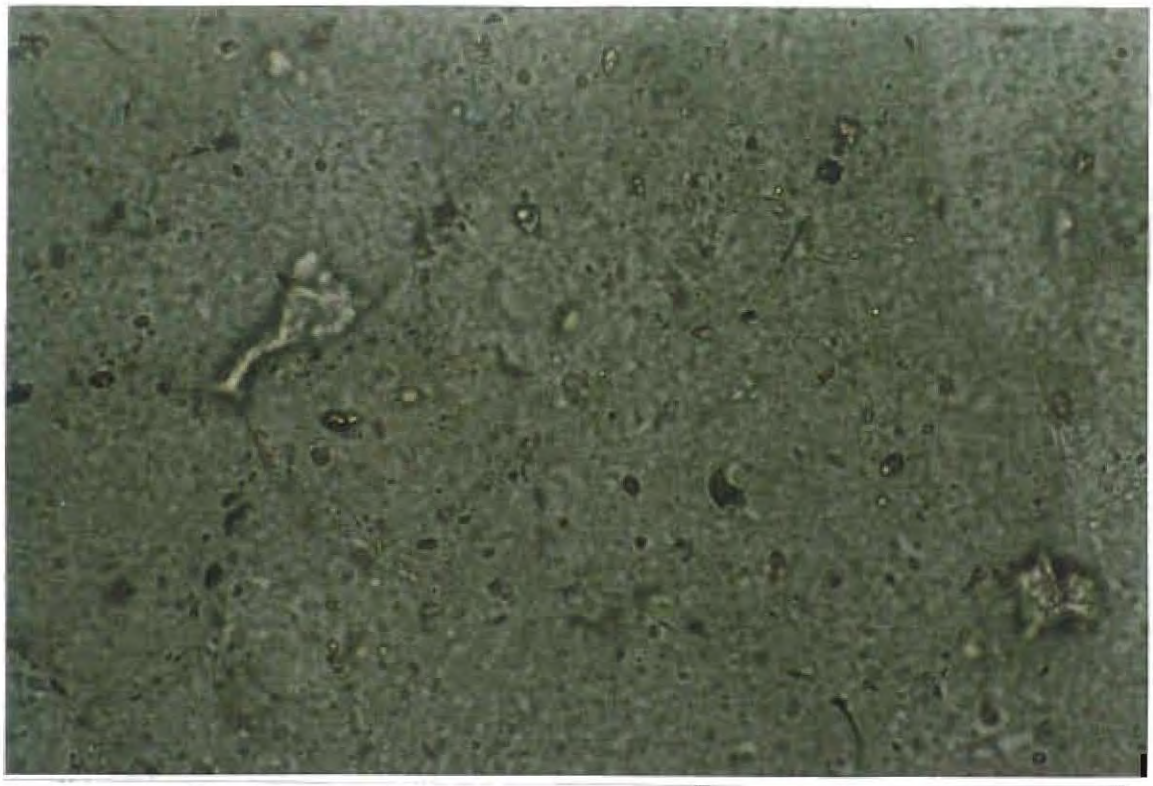
Almost all of the fluid inclusions studied occurred in quartz grains. Some fluid inclusions were observed in the calcite grains, but proved to be unsuitable for evaluation. Similarly, abundant fluid inclusions in blocky euhedral apatite crystals were too small to be effectively studied. Within thin quartz/pyrite/barite veins tiny fluid inclusions are common, particularly in the anhedral barite prisms, but were too small for evaluation.

5.1.2 Inclusion Petrography

The fluid inclusion distribution, size, types and contents were determined from an examination of the doubly polished thin sections. The origins of the inclusions were also determined (using criteria described by Roedder 1971, 1977, 1984). For simplicity the fluid inclusions were classified using phase relationships observed at room temperature (e.g. Nash, 1976, Khin Zaw, et.al., 1994).

The abundance of fluid inclusions varied considerably between samples, with nine (out of 35) samples having no workable inclusions. The proportion of primary, secondary and psuedo-secondary inclusions also varied considerably, with some samples only having secondary inclusions and odd samples having dominantly primary inclusions. The primary inclusions (Plate 5.1) are generally

(a) Larger, isolated primary inclusions of both liquid-rich and vapour-rich varieties.



(b) Large, isolated primary inclusions and planes of tiny secondary inclusions.

Plate 5.1 Primary fluid inclusions.

rare, typically being isolated, equi-dimensional and moderately sized (mostly 10 - 20 microns, but some up to 40 microns). Large, liquid-rich, secondary inclusions also occur, and contain halite, hematite and other daughter minerals (Plate 5.2). The secondary inclusions (Plate 5.3 and 5.4) are mainly small (typically less than 5 - 15, but up to 50 microns), with irregular but elongate morphologies, lying in planar arrays along healed fractures. Some of these planar arrays, in fact, may consist of primary inclusions lying on growth planes. However, in general, many of the quartz grains show signs of fracturing and deformation typical of the porphyry environment (Nash, 1976).

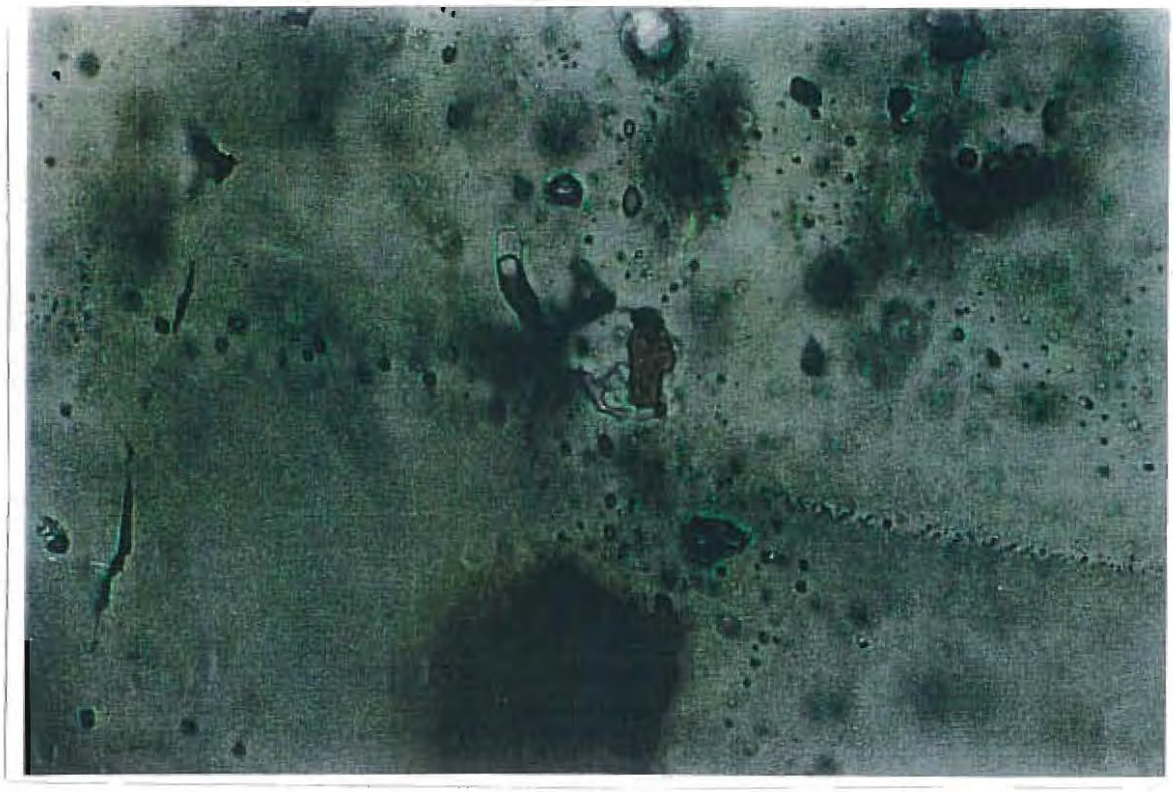
In some samples, fluid inclusion populations were highly variable, with vapour dominated inclusions occurring with single phase liquid only inclusions. This may indicate that necking (with or without leakage) has occurred (K. MacKenzie, pers. comm., 1995). However, some populations from several samples contain only vapour-rich inclusions (with no liquid-only inclusions) and may be due to trapping of a two phase fluid, indicative of boiling (Plate 5.3).

Four types of fluid inclusions were present in the Waisoi samples, these being:

Type I. Liquid-rich. These inclusions contain two fluid phases in which the liquid occupies more volume than the vapour (Plate 5.5a). Daughter minerals may be present, but are rare. With increased temperature these inclusions usually homogenise to a liquid.

The liquid-rich inclusions are the most common at Waisoi, and occur in almost all samples, from the intrusives to most of the quartz-rich vein stages. They appear to occur mainly in the silicification, main mineralisation and late mineralisation stages, but have also been observed in quartz veins associated with the sericitisation and carbonate stages. They can appear as primary inclusions, but more commonly occur as secondary inclusions on a variety of fracture planes indicating multiple phases of introduction.

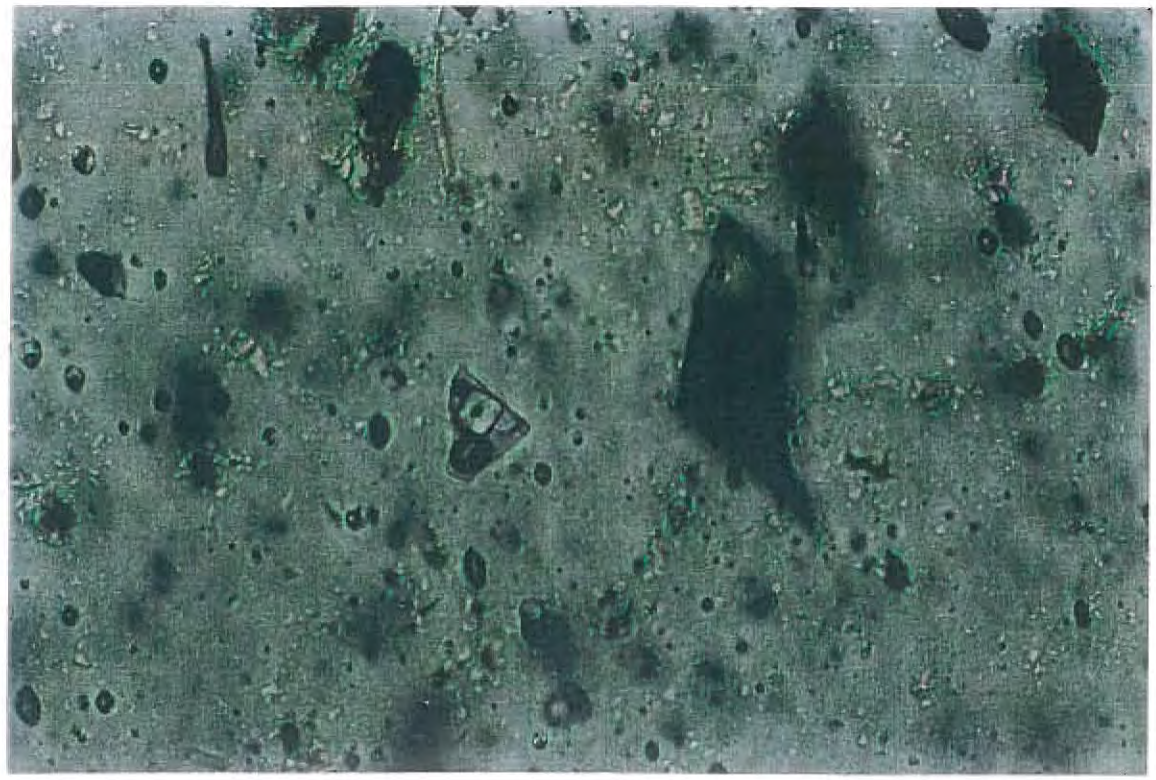
There appears to be a gradation in the liquid to vapour ratio from liquid-rich inclusions through to vapour-rich inclusions.



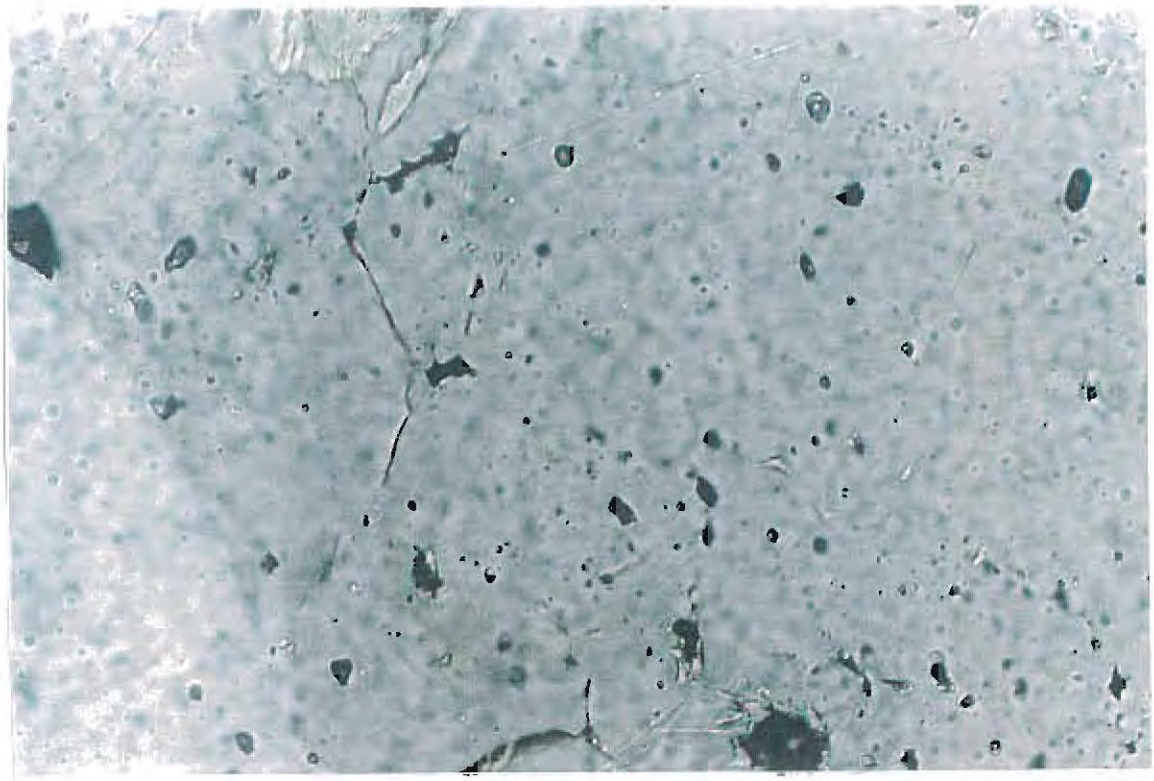
(a) Large secondary liquid-rich inclusions adjacent to planes of small secondary inclusions.

(b) Large secondary liquid-rich and vapour-rich inclusions, and some isolated primary inclusions.

Plate 5.2 Large secondary fluid inclusions.

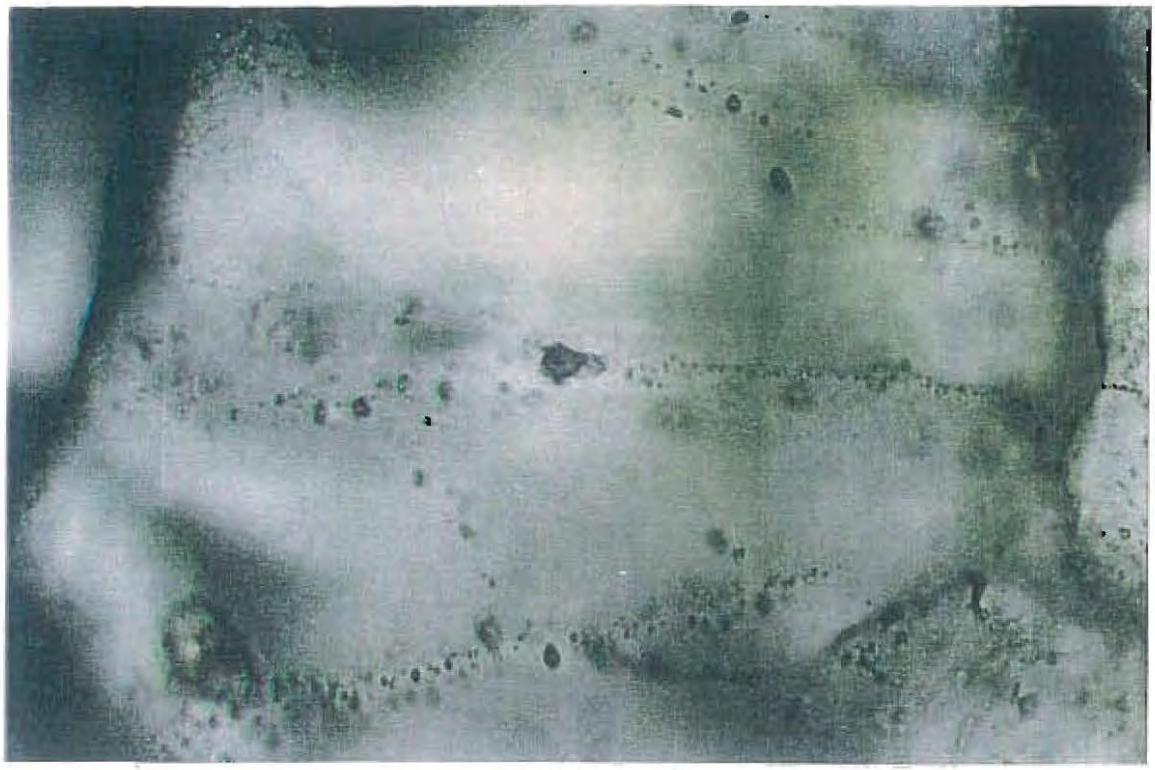


(a) Large secondary liquid-rich inclusions with halite and heamatite. Abundant vapour-rich inclusions with rare two phase liquid-rich dominated inclusions suggests trapping from a boiling solution.

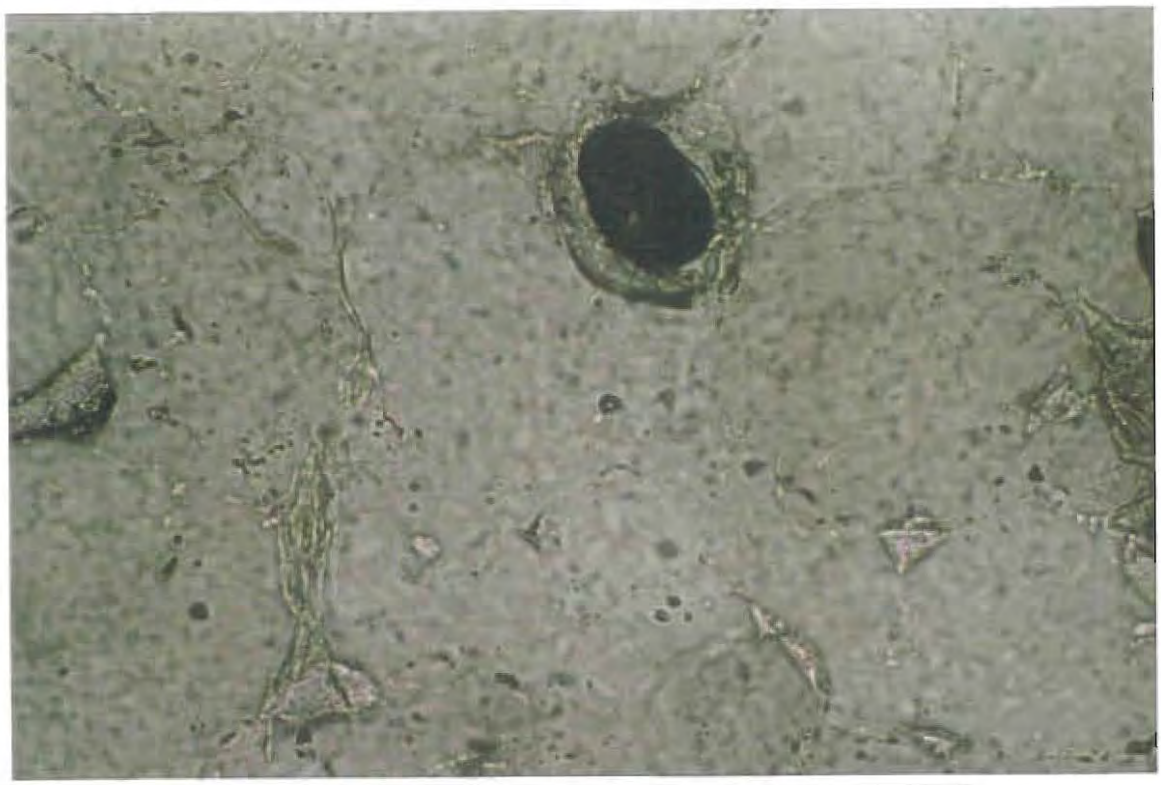


(b) Planes of tiny secondary inclusions with some larger liquid-rich secondary inclusions and rare primary inclusions.

Plate 5.3 Secondary fluid inclusions.

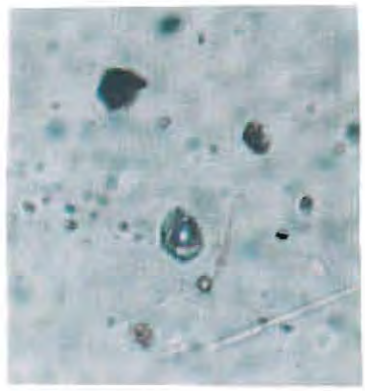


(a) Planes of tiny vapour-rich secondary inclusions with rare primary inclusions.

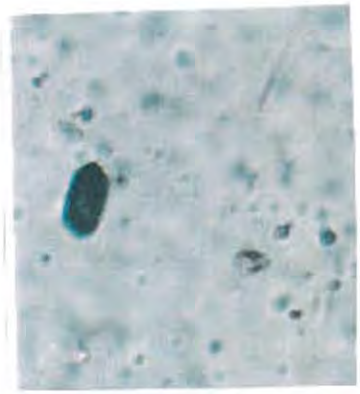


(b) Planes of tiny secondary inclusions with some larger secondary inclusions.

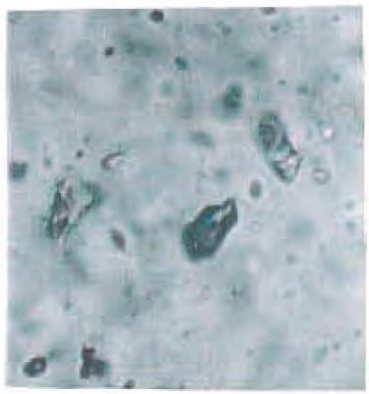
Plate 5.4 Small secondary fluid inclusions.



(a) Type I. Liquid-rich.



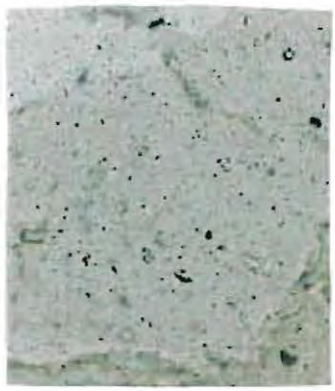
(b) Type II. Vapour-rich.



(c) Type II. Vapour-rich with daughter minerals.

(d) Type III. Halite-rich.

(e) Type III. Daughter minerals



(f) Type IV. CO_2-rich

Plate 5.5 Waisoi fluid inclusion types.

Type II. Vapour-rich. These inclusions generally contain two fluid phases, but with a majority of the volume occupied by vapour (Plate 5.5b). Rare hematite daughter minerals also occur (Plate5.5c).

Type II inclusions can be subdivided, on the basis of their homogenisation behaviour, into:

- Type IIa - homogenise to a liquid with the disappearance of the vapour bubble
- Type IIb - homogenise to a vapour with the disappearance of the liquid

The abundance of the Type II inclusions is extremely variable, with some samples containing significant numbers, while others contain very few. They tend to occur in quartz veins in the vicinity of the porphyry intrusions.

Type III. Halite-bearing. These inclusions contain two fluid phases, a liquid and a vapour, and one or more daughter minerals and are quite common in the Waisoi samples (Plate 5.5d). With increased temperatures these Type III inclusions generally homogenise to a liquid, into which the vapour and daughter minerals disappear (dissolve). In some cases the daughter minerals do not appear to be dissolving, and may reflect post-trapping changes (such as hydrogen diffusion - Nash, 1976).

Common daughter minerals (Plate 5.5e) include red to opaque, anhedral to euhedral (commonly triangular) hematite, clear, cubic crystals of halite, and slightly rounded, smaller grains of sylvite occurring with halite. There are several other daughter minerals that were not confidently identified, but may be anhydrite (rectangular with parallel extinction), magnetite/hematite (small, black and rounded) and calcite (square and highly birefringent).

Type III inclusions are common in the Waisoi samples, particularly in veins associated with mineralisation. However, not all mineralised veins contain daughter mineral-bearing fluid inclusions.

Type IV. CO_2-rich. These inclusions contain three fluid phases, with liquid CO_2 appearing at depressed temperatures. Such inclusions are very rare in the

Waisoi samples evaluated, but were observed in calcite veins in areas of strong to intense carbonate alteration (Plate 5.5f). Most of these inclusions could not be evaluated as the inclusions were too small (<4 microns).

These fluid inclusion types are summarised in Table 5.1.

Fluid inclusion		Phases at rooom temperature (25^{0}C)		Homogenisation
Type	Subtype	Dominant	Types	behaviour
I		Liquid	liquid + vapour +/- daughters	liquid
II	IIa	Vapour	vapour + liquid +/- daughters	liquid
	IIb	Vapour	vapour + liquid +/- daughters	vapour
III		Liquid	liquid + vapour + daughters	liquid
IV		Liquid	liquid + vapour +liquid CO_2	liquid

Table 5.1 Summary of fluid inclusion types and sub-types, their dominant and secondary phases, and their homogenisation behaviour.

Type I, II and III inclusions were observed in almost every sample studied from Waisoi, but in varying numbers. The Type III inclusions tended to be less common in samples from the more peripheral areas of the mineralisation, and have not been observed in the carbonate stage veins. They were also rare in the late mineralisation stage veins. Type IV inclusions are rare and occur only in areas close to abundant, intense carbonate alteration.

5.1.3 Homogenisation and Freezing Temperatures

Fluid inclusion microthermometry heating and freezing measurements were made on suitable inclusions using a USGS gas-flow heating/freezing stage. Heating and freezing measurements were completed using the procedures described by Bodnar and Beane (1980), Bodnar (1982), Reynolds and Beane (1985), and Sterner et.al. (1988). Temperature errors were +/-5^{0}C for heating measurements and +/- 0.3^{0}C for freezing measurements. Accuracies were maintained by calibration with the critical point of water (374.6^{0}C), and the freezing point of water (0.0^{0}C) on synthetic fluid inclusions. In practise the measurement of fluid inclusion homogenisation and freezing temperatures is likely to be less precise (Losada-Calderon, 1992) due to:

- the smallness of most of the inclusions,

- variations in the size and shape of the inclusions,
- variations in the sample thickness,
- variations in the position of the sample in the gas-flow, and
- variations in the position of the thermocouple relative to the inclusion being evaluated.

The inclusions most commonly used for microthermometry heating and freezing measurements were two phase, liquid-rich inclusions with vapour constituting about 20% of the volume of the inclusion at room temperature.

Salinities for halite-undersaturated inclusions were calculated from the freezing point depression measurements using equations determined by Potter et.al. (1978). For halite-saturated inclusions, salinities were calculated from the temperature measurements for the halite to dissolve, using the equations determined by Bodnar et.al (1989). Both methods do not consider the effects of other salts, and thus include some inaccuracies.

5.1.3.1 Homogenisation Temperatures

Homogenisation temperatures have not been corrected for the effects of pressure since burial depths are uncertain. If it is assumed that quasi-lithostatic conditions and a depth of about 2 km (pressure of about 75 bars) are typical of a porphyry formation environment, then an approximate pressure correction of about 60 ^{0}C could be added to the homogenisation temperature (K. MacKenzie pers.comm., 1995). This would be a minimum temperature correction (for lithostatic pressure adjustments) as many inclusions have no upper limits of the homogenisation temperature.

Most samples contained fluid inclusions in quartz with a wide range of (non pressure corrected) homogenisation temperatures (Table 5.2), with the maximum values exceeding the maximum temperature of the heating stage (about 500 ^{0}C). Although 37% of the fluid inclusions had homogenisation

SAMPLE NOS	HOMOGENISATION TEMPERATURES (°celcius)			FREEZING POINTS (° celcius)				EQUIVALENT SALINITY			NOTES
	No	Measured Temperatures	Mean	Median	No	Measured Temperatures	Mean	wt% NaCl*			
								Range		Mean	
WSD214 232.5	9	237 145 368 366 370 374 410 412 422	356	370	3	-6.6 -6.8 -12.7	-8.7	11.6 - 22.8		15.4	Mostly 2^{o} rare 1^{o} variable LV including L only and V only incl hal syl dt min
WSD217 200.9	6	251 262 264 276 278 278	268	269							Rare small 2^{o} incl no dt min
WSD217 95.0	6	235 305 373 385 >450 >450	>368	379	2	-16.3 -21.2	-18.8	30 - 40.5		35.1	Abundant 2^{o} and rare large 1^{o} incl some V rich , hal dt min
WSD217 262.5	3	>460 >460 >460	>460	>460							Very small L rich 1^{o} incl
WSD220 267.0	11	235 393 408 411 413 418 420 424 431 432 >450	>403	418	2	-14.2 -16.1	-15.2	25.7 - 29.5		27.6	L rich 1^{o} incl, variable size, hal +/- hem dt min
WSD228 107.4	7	309 320 322 324 339 343 356	330	324	2	-12.9 -13.2	-13.1	23.2 - 23.8		23.5	Abundant small 2^{o} incl - lesser 1^{o}, widespread necking, hal dt min
WSD232 122.9	6	271 290 383 385 395 >450	>362	384							Rare L rich 2^{o} incl containing hal dt min
WSD228 117.4	12	336 392 395 439 462 >465 >465 >465 >465 >465 >465 >465 >46	>440	>465	2	-13.7 -13.9	-13.8	24.8 - 25.2		25	Abundant 2^{o} incl with variable LV common V rich incl hal +/- syl dt min
WSD238 137.8H	10	396 435 455 >465 >465 >465 >465 >465 >465 >465 >465	>454	>465	3	-13.2 -16.4 -24.2	-17.9	23.8 - 47.7		33.4	Abundant 1^{o} and 2^{o} incl variable L V incl V rich common hal +/- hem dt min
WSD228 320.75	5	208 220 220 224 349	244	220							Rare small L rich 1^{o} incl hal dt min
109558	2	>460 >460	>460	>460							Very rare isolated 1^{o} incl
109588											No inclusions found
WN2 193.1	18	320 415 422 460 >470 >470 >470 >470 >470 >470 >470 >470 >470 435 512 512 517 528 538	>470	>470	5	2.2 -12.4 -12.6 -16.4 -16.9	-11.2	0 - 22.3		20	Abundant 2^{o} incl, variable size with constant LV hal + hem dt min contains clathrate
WSD212 355.3	7	393.7 337.7 >450 394 377.9 388 455						>40.8 - >45.5			Vapour homogenises to liquid, salt disappearing,
											vapour about to disappear, vapour homogenises to liquid
WSD238 137.8	13	338.7 361.8 393.8 448.7 450 455 461.8 495.8 481.1 446.8			4	-3.0 -4.0 -4.9 -6.9					Homogenises to liquid, except Hm,
		>525 493.3 510									
109594	7	406.8 547.8 238.8 >500 >550 472.3 >555			2	-45 -26		0 - 22.4			Vapour disappears, Th not clear, but homogenises to vapour, homogenises to liquid,
											vapour about to disappear, tiny vapour bubble still present, homogenises to liquid
WSD234 110.9	6	383 444 435 >510 450 450									Homogenises to vapour, homogenises to liquid
WN1 225.9	3	454.3 423 >531						>59.4			Vapour to liquid @ 454.3, salt disappearing, homogenises to liquid,
											vapour homogenising to liquid
WSD228 117.4	7	391.7 443.2 477.7 309 324 356.9 510.9			3	-2.7 -14.8 -32.6		4.5 - 18.3			Homogenises to liquid
WSD212 80.1	6	328.6 329.7 348.8 373 354.3 348.8			1	-2.3		3.9 - 46.3			Vapour to liquid (354.3), Salt to liquid (402.1), vapour to liquid, homogenises to vapour,
											vapour to liquid (348.8), Hm about to disppear (531.0)
WSD214 232.5	3	>530.7 507 >530.7			2	-2.5 -8.8		4.2 - 57.2			Vapour close to disappearing,vapour and salt to liquid, decrepitation @ 518.7,
											vapour and salt close to disappearing
WSD234 106.35	5	196 220 >524.3 >524.3 456.5									Vapour close to disappearing, vapour to liquid

* Equivalent Salinities calculated according to the method of Potter et al (1978)

Abbreviations

1^{o}	primary
2^{o}	secondary
L	liquid
V	vapour
incl	inclusion/s
hal	halite
syl	sylvite
hem	hematite
dt min	daughter mineral/s

TABLE 5.2 Summary of the fluid inclusion microthermometry heating and freezing measurements from Walsoi.

TABLE 5.2(a): DETAILS OF THE FLUID INCLUSION MICROTHERMOMETRIC HEATING AND FREEZING MEASUREMENTS FROM NAMOSI.

SAMPLE NOS	HOST MINERAL	VEIN STAGE	FL NO	LENGTH	PHASES	TYPE	Th	Tlm	Tfm	Td-Sal	Salinty	Remarks
WSD212@80.1	Vein quartz	Silicification (III)	(a)	6	L-V	P - I						
			(b)	13	L-V	P - I	328.6					
			(c)	9	L-V	P - I						
			(d)	6	L-V	P - I	329.7	-2.3			3.9	
			(e)	13	L-V	P - IIa	348.8					Vapour to liquid
			(f)	10	L-V	P - IIb	373					Homogenises to vapour
			(g)	5	L-V-NaCl	P - III	354.3			402.1	46.3	Vapur to liquid (354.3), Salt to liquid (402.1)
			(h)	7	L-V-Hm	P - III	348.8					Vapour to liquid (348.8), Hm about to disappear (531.0)
WSD212@355.3	Vein quartz	Silicification (III)	(a)	19	L-VLNaCl-Hm	P - III	393.7			>393.7	>45.5	Vapour homogenises to liquid, salt disappearing
			(b)	15	L-V-NaCl-Hm	P - III	337.7			337.7	>40.8	Vapour homogenises to liquid, salt disappearing
			(c)	9	L-V	P - IIa	>450					Vapour about to disappear
			(d)	12	L-V	P - IIa	394					Vapour homogenises to liquid
			(e)	12	L-V	P - IIa	377.9					Vapour homogenises to liquid
			(f)	9	L-V	P - IIa	389					Vapour homogenises to liquid
WSD214@232.5	Quartz	Silicification (III)	(a)	10	L-V	P - I						
			(b)	6	L-V	P - I		-2.5			4.2	
			(c)	15	L-V	P - I		-8.8			12.6	
			(d)	25	L-V	P - IIa	>530.7					Vapour close to disappearing
			(e)	12	L-V-NaCl	P - III						
			(f)	16	L-V-NaCl-Hm	P - III	507			507	57.2	Vapour and salt to liquid, decrepitation @ 518.7
			(g)	9	L-V-NaCl	P - III	>530.7			>530.7	57.2	Vapour and salt close to disappearing
WSD214@232.5	Vein quartz	Silicification (III)	(a)	20	L-V	P - I	237					
			(b)	5	L-V	S - I	245					
			(c)	8	L	S - I		-6.6			11.6	Rare liquid only inclusion
			(d)	15	L-V	P - IIb	410					Rare useable primary inclusion - homogenises to vapour
			(e)	9	L-V	S - IIa	412					Homogenises to liquid
			(f)	12	L-V-NaCl	S - III	422					
			(g)	6	L	S - I		-6.8				Rare liquid only inclusion
			(h)	30	L-V	S - I	368					
			(i)	7	L-V	S - I	374					
			(j)	13	L-V-NaCl	S - III	368					
			(k)	7	L-V	S - IIb	370	-12.7			22.8	Homogenises to vapour
			(l)	7	V	S - IIa						
WSD217@95.0	Quartz stockwork	Silicification (III)	(a)	40	L-V	P - IIb	305					Homogenises to vapour
			(b)	30	L-V-NaCl	S - III		-21.2			40.5	
			(c)	10	L-V	S - IIa	235					Homogenises to liquid
			(d)	5	L-V	S - IIa	>450					Homogenises to liquid
			(e)	20	L-V-NaCl	S - III		-16.3			30	
			(f)	9	L-V	S - IIa	>450					Homogenises to liquid
			(g)	12	L-V	S - IIb	373					Homogenises to vapour
			(h)	6	L-V	S - I	385					
WSD217@200.9	Quartz	Albite/Sericite (I/II)	(a)	3	L-V	S - I	264					
			(b)	5	L-V	S - I	251					
			(c)	4	L-V	S - IIa	278					Homogenises to liquid
			(d)	5	L-V	S - I	276					
			(e)	4	L-V	S - I	278					
			(f)	4	L-V	S - I	262					

WSD217@262.5	Quartz	Potassic (IV)	(a)	3	L+/-V	P - I	>460					
			(b)	3	L+/-V	P - I	>460					
			(c)	4	L+/-V	P - I	>460					
WSD220@267.0	Vein quartz	Potassic (IV)	(a)	7	L-V	S - I	408					
			(b)	7	L-V-NaCl-Hm	P - III	>450					
			(c)	5	L-V-NaCl-Hm	P - III		-16.1			29.5	
			(d)	10	L-V-NaCl	P - III		-14.2			25.7	
			(e)	40	L-V	P - I	235					
			(f)	8	L-V	P - I	393					
			(g)	7	L-V	P - IIa	432					Homogenises to liquid
			(h)	14	L-V	P - I	418					
			(i)	7	L-V-NaCl	P - III	424					
			(j)	28	L-V-NaCl-Hm	P - III	431					
			(k)	4	L-V	P - IIb	420					Homogenises to vapour
			(l)	8	L-V	P - I	413					
			(m)	6	L-V	P - I	411					
WSD228@107.4	Quartz	Chlorite (V)	(a)	4	L-V	P - I	324					
			(b)	6	L-V-NaCl	S - III	343	-12.9			23.2	
			(c)	5	L-V	S - I	309					
			(d)	4	L-V	S - I	320					
			(e)	9	L-V	S - I	339					
			(f)	12	L-V	S - I	322					
			(g)	5	L-V	S - I	356					
			(h)	8	L-V-Hm	P - III		-13.2			23.8	
WSD228@117.4	Vein quartz	Potassic (IV)	(a)	21	L-V	P - IIb		-2.7			4.5	
			(b)	16	L-V	P - IIa	391.7	-14.6	-32.6		18.3	Homogenises to liquid
			(c)	7	L-V	P - IIa	443.2					Homogenises to liquid
			(d)	8	L-V	P - IIa	477.7					Homogenises to liquid
			(e)	6	L-V	P - IIa	309					Homogenises to liquid
			(f)	7	L-V	P - IIa	324					Homogenises to liquid
			(g)	7	L-V	P - IIa	356.9					Homogenises to liquid
			(h)	13	L-V	P - IIa	510.9					Homogenises to liquid
WSD228@117.4		Potassic (IV)	(a)	10	L-V-NaCl	S - III	462					
			(b)	14	L-V-NaCl	S - III	>465					
			(c)	9	L-V	S - IIb	395					Homogenises to vapour
			(d)	18	L-V	S - IIb	>465					Homogenises to vapour
			(e)	7	L-V-NaCl	S - III	>465	-13.7			24.8	
			(f)	15	L-V-NaCl	S - III	>465					
			(g)	5	L-V	S - IIb	336					Homogenises to vapour
			(h)	12	S - III	S - III	>465	-13.9			25.2	
			(i)	20	L-V	S - IIb	392					
			(j)	13	L-V	S - IIb	>465					Homogenises to vapour
			(k)	8	L-V-NaCl	S - III	>465					
			(l)	5	L-V-NaCl	S - III	439					
			(m)	6	L-V	S - I		-32.6				
WSD228@320.75(H)		Early Carbonate (V	(a)	4	L-V	P - I	349					
			(b)	5	L-V	P - I	208					
			(c)	3	L-V-NaCl	P - III	220					
			(d)	3	L-V-NaCl	P - III	220					
			(e)	4	L-V	S - I	224					

DETAIL OF THE FLUID INCLUSION STUDY SUMMARISED IN TABLE 5.2

WSD232@122.9		Chlorite (V)	(a)	5	L-V	S - I	>450					
			(b)	6	L-V	S - I	383					
			(c)	9	L-V	S - I	271					
			(d)	4	L-V-NaCl	S - III	290					
			(e)	7	L-V-NaCl	P - III	395					
			(f)	4	L-V	S - I	385					
WSD234@106.35	Quartz	Potassic (IV)	(a)	5	L-V	S - IIa	196					Vapour to liquid
			(b)	15	L-V	S - IIa	220					Vapour to liquid
			(c)	13	L-V	P - I						
			(d)	11	L-V	P - I						
			(e)	7	L-V	P - IIa	>524.3					Vapour close to disappearing
			(f)	6	L-V	P - IIa	>524.3					Vapour close to disappearing
			(g)	4	L-V	P - IIa	456.5					Vapour to liquid
WSD234@110.9	Quartz phenocryst	Potassic (IV)	(a)	16	L-V	P - I						
			(b)	7	L-V	P - I						
			(c)	35	L-V-NaCl	P - III						
			(d)	15	L-V	P - IIb	383					Homogenises to vapour
			(e)	12	L-V	P - IIb	444					Homogenises to vapour
			(f)	4	L-V	P - IIa	435					Homogenises to liquid
			(g)	6	L-V	P - IIa	>510					Homogenises to liquid
			(h)	22	L-V	P - I						
			(i)	10	L-V	P - IIb	450					Homogenises to vapour
			(j)	16	L-V	P - IIb	450					Homogenises to vapour
WSD238@137.8	Quartz phenocryst	Potassic (IV)	(a)	12	L-V-Hm?	P - III	455					Homogenises to liquid, except Hm
			(b)	8	L-V	P - IIa	495.8					Homogenises to liquid
			(c)	18	L-V-Hm	P - III	481.1					Homogenises to liquid
			(d)	9	L-V-Hm	P - III	446.8					Homogenises to liquid
			(e)	13	L-V	P - IIa	>525					Homogenising to liquid
			(f)	21	L-V	P - IIa	483.3					Homogenises to liquid
			(g)	23	L-V	P - IIa	>510					Homogenising to liquid
WSD238@137.8	Vein quartz	Potassic (IV)	(a)	3	L-V	S - IIb	393					
			(b)	9	L-V	P - I	453	-4.9				
			(c)	9	L-V	P - I		-3	-4.9			
			(d)	9	L-V-NaCl-Hm	P - III	461.8					
			(e)	9	L-V-NaCl-Hm	P - III	391.8			461.8		
			(f)	4	L-V-NaCl-Hm	S - III	448.7			>550		
			(g)	3	L-V-NaCl	S - III	>550					
			(h)	9	L-V-NaCl-Hm	S - III	448.7					
			(i)	8	L-V	S - IIa	361.8					Homogenising to liquid
			(j)	16	L-V	S - I	338.8	-3				
			(k)	3	L-V	P - IIb		-6.9				Homogenises to vapour
			(l)	6	L-V	P - IIb		-2.2				Homogenises to vapour
			(m)	6	L-V-NaCl-Hm	P - III	361.8		-3	391.8		
			(n)	5	L-V-NaCl	S - III	448.7					
			(o)	9	L-V	S - IIa	448.7	-4.9				Homogenising to liquid
			(p)	7	L-V	S - I		-4				

DETAIL OF THE FLUID INCLUSION STUDY SUMMARISED IN TABLE 5.2

WSD238@137.8(H)		Potassic (IV)	(a)	4	L-V	S - I	398					
			(b)	10	L-V-NaCl-Hm	S - III	455	-13.2			23.8	
			(c)	6	L-V-NaCl	P - III	>465					
			(d)	8	L-V	S - IIa	>465					Homogenising to liquid
			(e)	5	L-V-NaCl-Hm	P - III	>465	-16.4				
			(f)	6	L-V	P - I	435					
			(g)	8	L-V	P - I	>465					
			(h)	4	L-V-NaCl-Hm	P - III	>465					
			(i)	7	L-V	S - I	>465					
			(j)	10	L-V	s - IIa	>465					Homogenising to liquid
			(k)	5	L-V-NaCl-Hm	S - III		-24.2			47.7	
109558		Potassic (IV)	(a)	25	L-V	P - IIa	>460					Vapour disappearing
			(b)	40	L-V	P - IIa	>460					Vapour disappearing
109588		Chlorite (V)										No useable inclusions
109594	Quartz phenocryst	Potassic (IV)	(a)	12	L-V	P - IIa	406.8					Vapour disappears
			(b)	9	L-V	P - I		-45				
			(c)	8	L-V	P - IIb						Th not clear, but homogenises to vapour
			(d)	25	L-V	P - I						
			(e)	19	L-V	P - IIa	547.8					Homogenises to liquid
			(f)	19	L-V	S - I	238.8	-20			22.4	
			(g)	15	L-V	P - I	>500					Vapour about to disappear
			(h)	8	L-V	P - I	>550					Tiny vapour bubble still present
			(i)	9	L-V	P - I	472.3					Homogenises to liquid
			(j)	9	L-V	P - I	>555					Tiny vapour bubble still present
WN2@193.1		Potassic (IV)	(a)	15	L-V-NaCl-Hm	S - III	422	-12.6				
			(b)	11	L-V	S - I	>470					
			(c)	50	L-V-NaCl-Hm	S - III	>470	-12.4				
			(d)	7	L-V-NaCl	S - III	>470	-16.4				
			(e)	5	L-V-NaCl	S - III	>470	-16.9			22.3	
			(f)	8	L-V	S - I	>470					
			(g)	10	L-V-NaCl-Hm	S - III	>470					
			(h)	20	L-V	S - I	>470					
			(i)	18	L-V-NaCl-Hm	P - I	>470					
			(j)	5	L-V-NaCl	P - I		2.2			0	
WN?225.9	Vein Quartz	Potassic (IV)	(a)	18	L-V-Hm	P - III						
			(b)	22	L-V-NaCl	P - III	454.3			>525.9	>59.4	Vapour to liquid @ 454.3, salt disappearing
			(c)	31	L-V	P - I						
			(d)	5	L-V	P - IIa	423					Homogenises to liquid
			(e)	9	L-V	P - IIa	>531					Vapour homogenising to liquid

Th: Homogenisation temperature
Tlm: Last ice melting
Tfm: First ice melting
Td-Sal: Temperature of dissolution of salt
Hm: Hematite
L: Liquid (H_20)
FI: Fluid inclusion

INCLUSION TYPES

I	Liquid rich
IIa	Vapour rich, homogenising to a liquid
IIb	Vapour rich, homogenising to a vapour
III	Halite bearing
IV	CO_2 rich

DETAIL OF THE FLUID INCLUSION STUDY SUMMARISED IN TABLE 5.2

P: Primary
S: Secondary
Sal: Salinity
Salinity from freezing point depression based on equarion of Bodnar (1993)
Salinity (NaCl equiv, wt, %)+1.78*t-0.000557t*.*
Salinity from temperature of melting based on equation of Potter et al. (1977)
Salinity (NaCl equiv, wt, %)= 26.218+0.0072*t=0.000106*t*=0.05

VEIN STAGES

I	Albitisation
II	Sericitisation
III	Silicification
IV	Potassic (Main mineralisation)
V	Chlorite (Late mineralisation)
VI	Early carbonate
VII	Late carbonate

DETAIL OF THE FLUID INCLUSION STUDY SUMMARISED IN TABLE 5.2

temperatures in excess of the heating stage capacity, the frequency distribution for the remainder of the inclusions (Figure 5.1) show a series of homogenisation temperatures between 145 and 547.8^{0}C. Peaks in the distribution occur at 220 - 240, 260 - 280, 320 - 340, 380 - 400, and 420 - +460^{0}C.

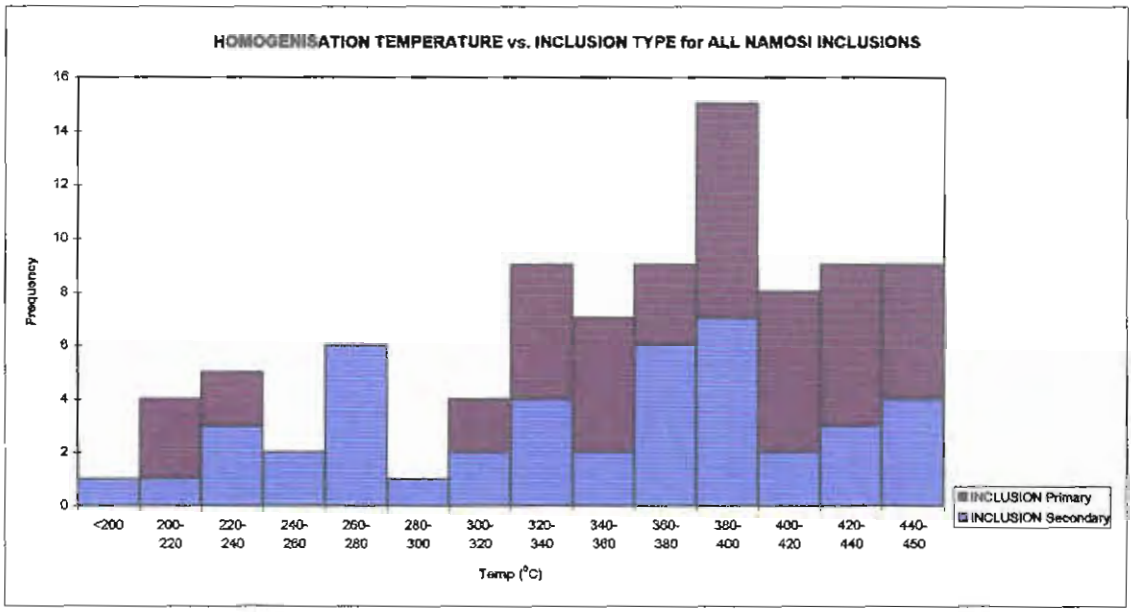
A comparison of the homogenisation temperatures and the host vein type shows the early porphyry-style veins (sericitisation, silicification and early mineralisation) contain an abundance of inclusions with high homogenisation temperatures (+460^{0}C). The main mineralisation stage veins (quartz with bornite +/- chalcopyrite) also contain a high proportion of fluid inclusions with daughter minerals. The late mineralisation stage veins (quartz with chalcopyrite) tend to have many inclusions in the 380 to 460^{0}C range with a few in the +460^{0}C range. The early carbonate stage veins (quartz with carbonate and chalcopyrite) have inclusions with homogenisation temperatures of 260 to 350^{0}C, while the late carbonate veins tend to have lower homogenisation temperature inclusions (200 to 240^{0}C).

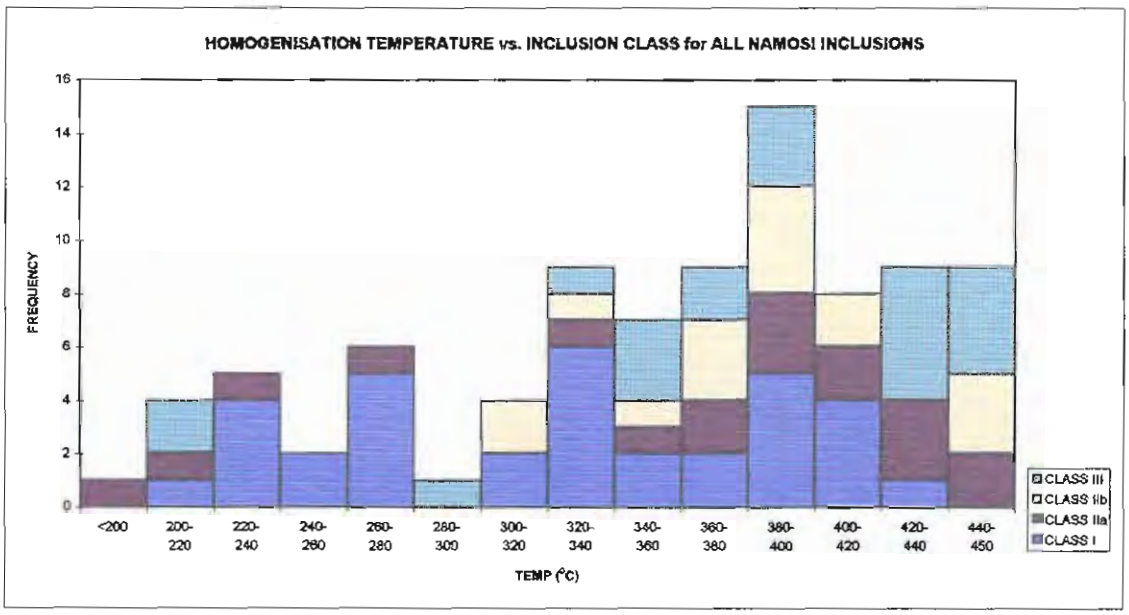
Most of the quartz grains in the early porphyry stage veins also contain fluid inclusions (secondary) which have lower homogenisation temperatures. These were probably caused by fracturing and fluid passage during the later stages of the porphyry alteration and mineralisation.

5.1.3.2 Freezing Temperatures and Salinities

Freezing temperatures were obtained for 35 fluid inclusions from nine samples (Figure 5.2). The remaining samples contained no inclusions of a size that allowed ice melting temperatures to be observed. Most of the melting temperature data was obtained from fluid inclusions which contained daughter minerals. The few inclusions containing no daughter minerals gave melting temperatures between -6.6 and -6.8^{0}C, corresponding to salinities of 11.6 to 12.0 wt.% NaCl equivalent.

Of the 35 fluid inclusions for which ice melting point measurements were made, 26 were halite-saturated and contained daughter minerals, and nine inclusions contained no daughter minerals. The inclusions with no daughter minerals appeared to group to three, narrow-ranges of ice melting temperatures, namely





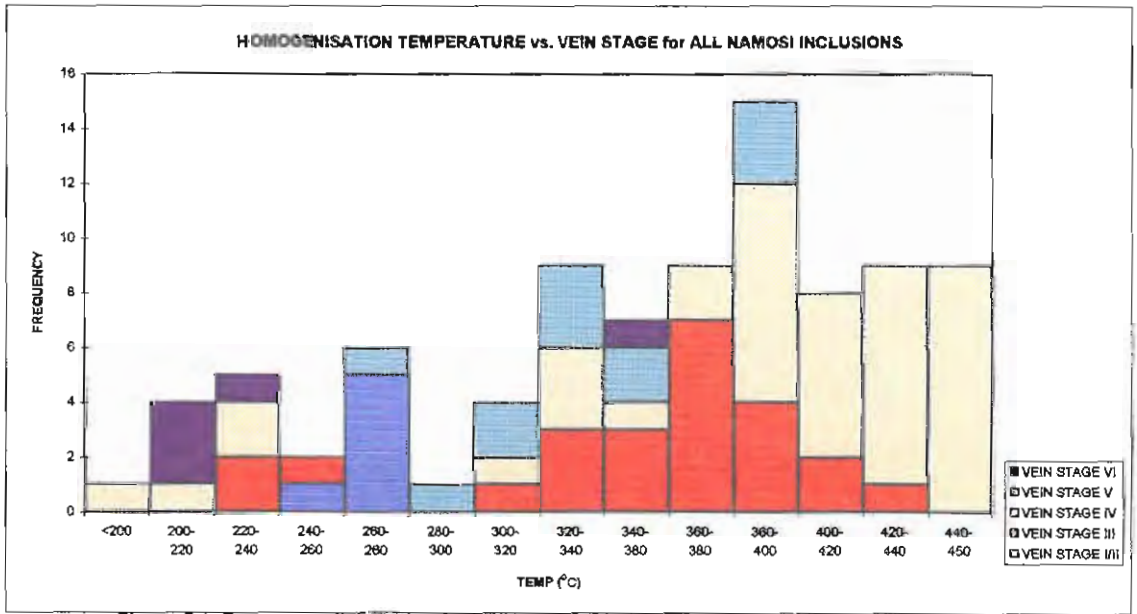


Figure 5.1 Frequency distribution for homogenisation temperatures for fluid inclusions from Waisoi.

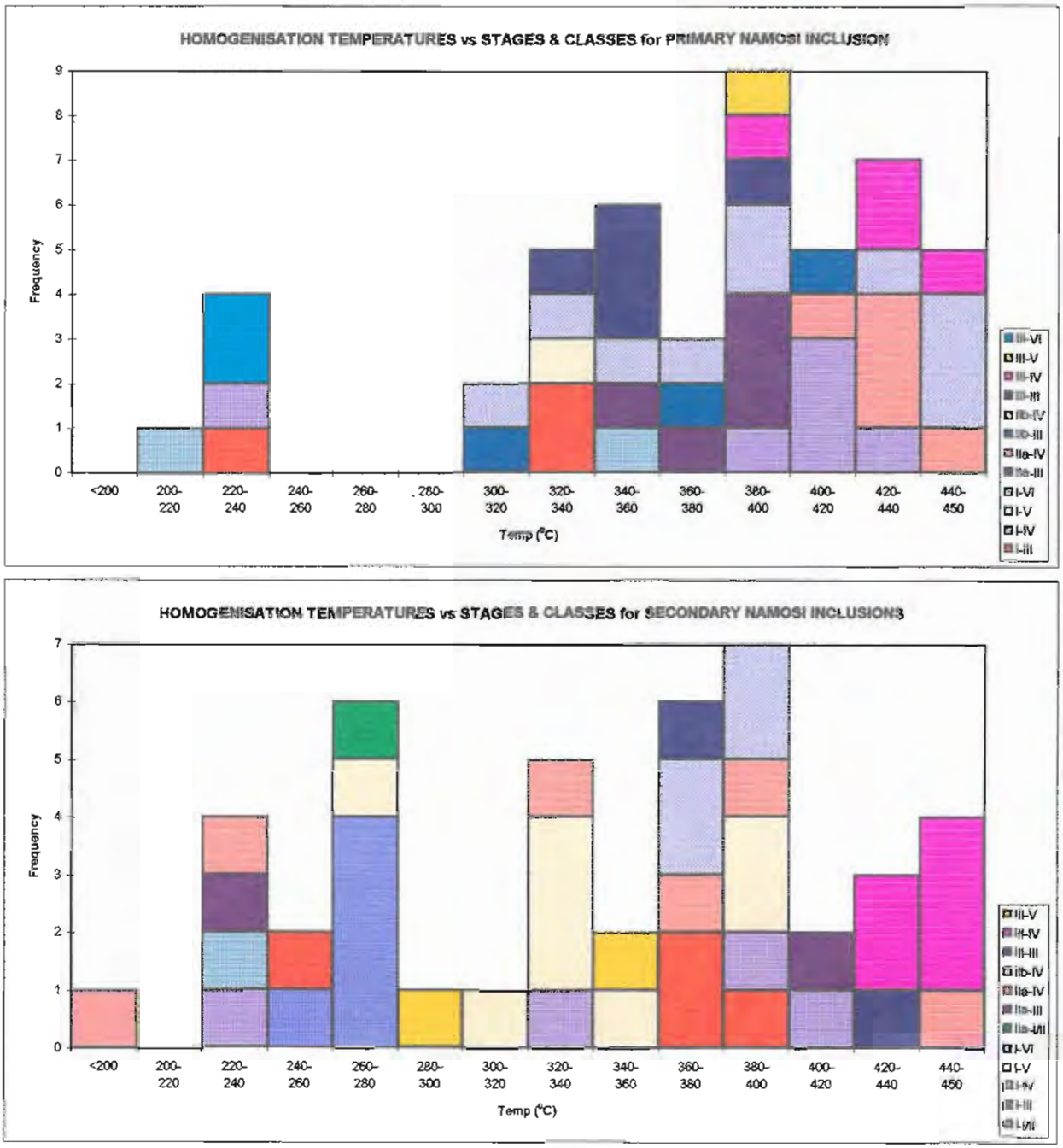


Figure 5.1a Frequency distribution for homogenisation temperatures vs class and stage for primary and secondary Waisoi inclusions

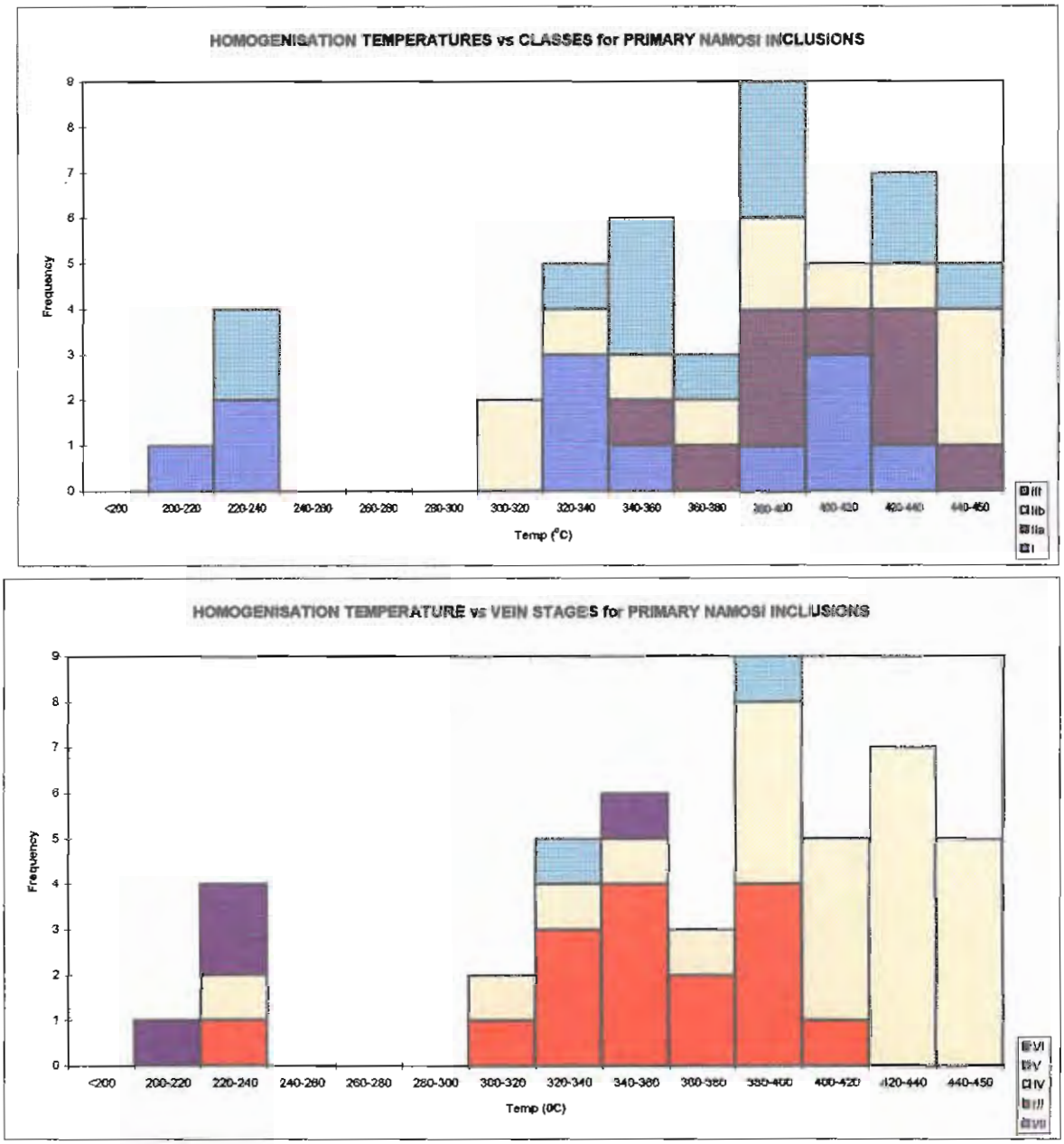


Figure 5.1b Frequency distribution for homogenisation temperatures for Walsol primary inclusion.

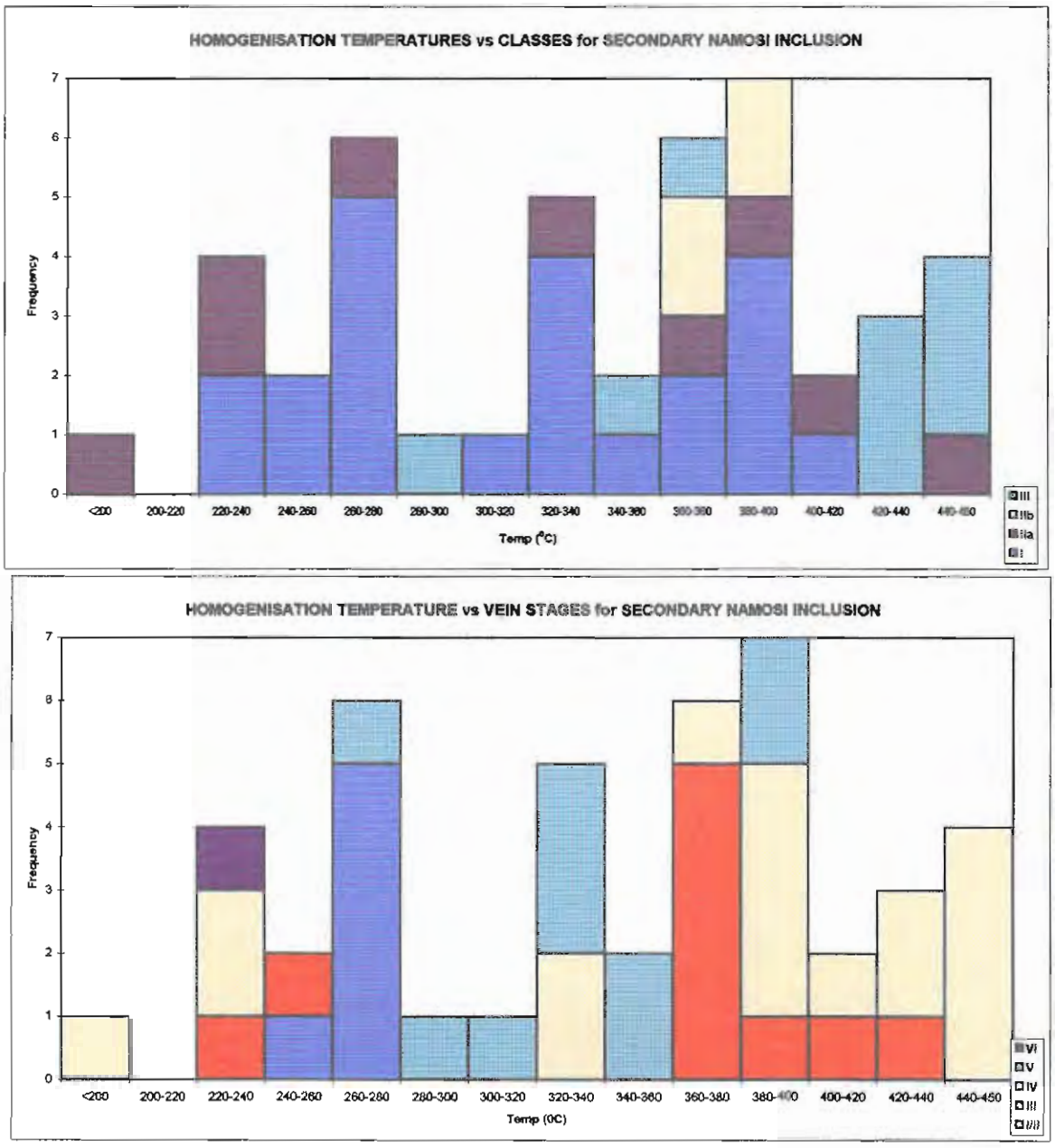
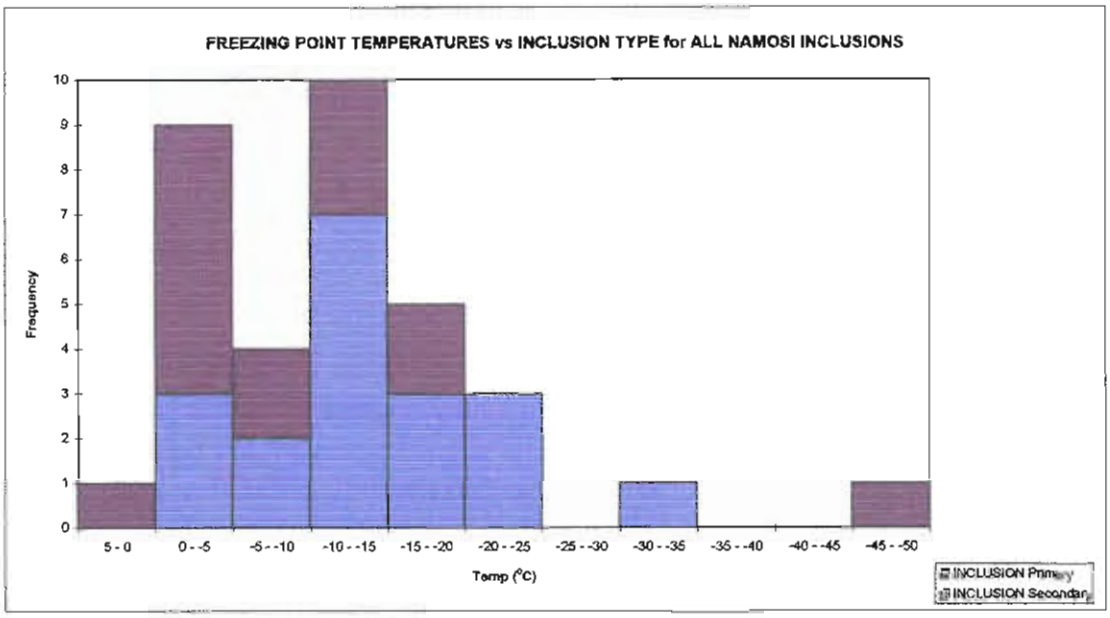
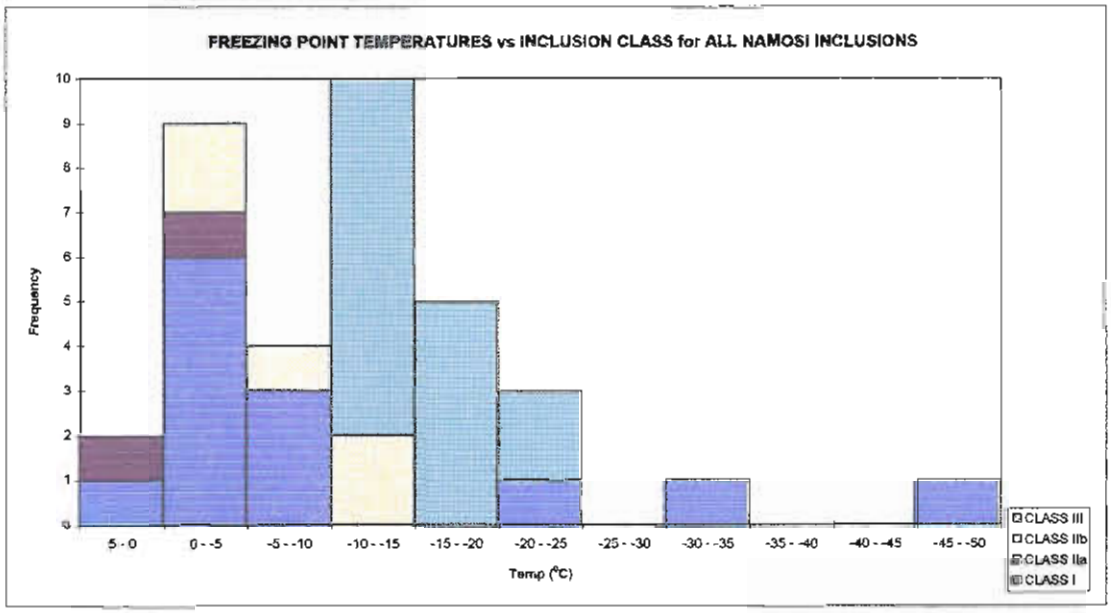


Figure 5.1c Frequency distribution for homogenisation temperatures for Waisoi secondary inclusions.





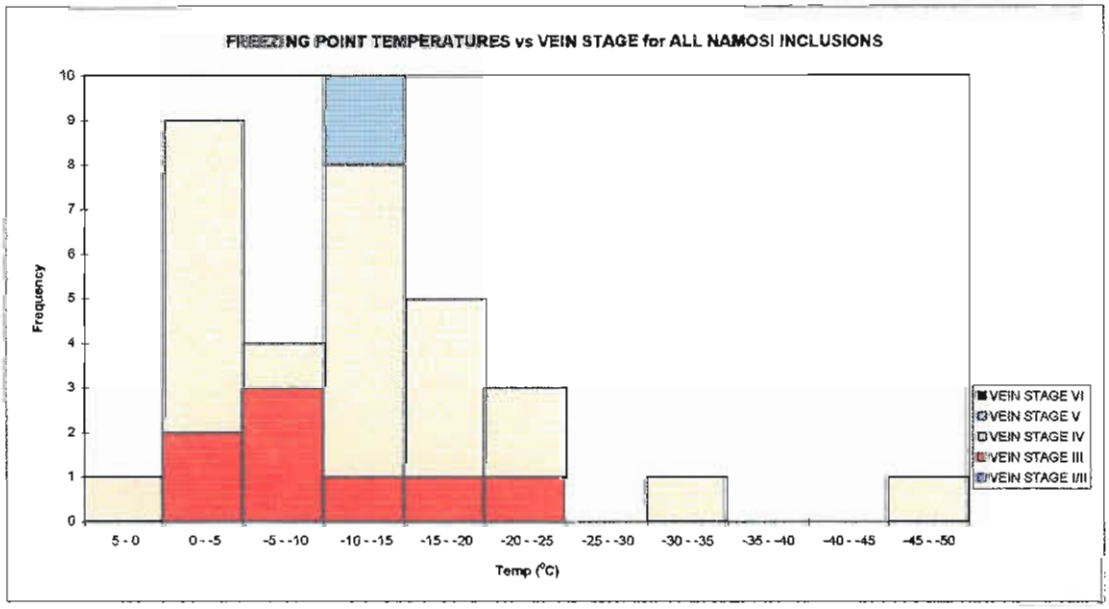


Figure 5.2 Frequency distribution for freezing points of fluid inclusions from Waisoi.

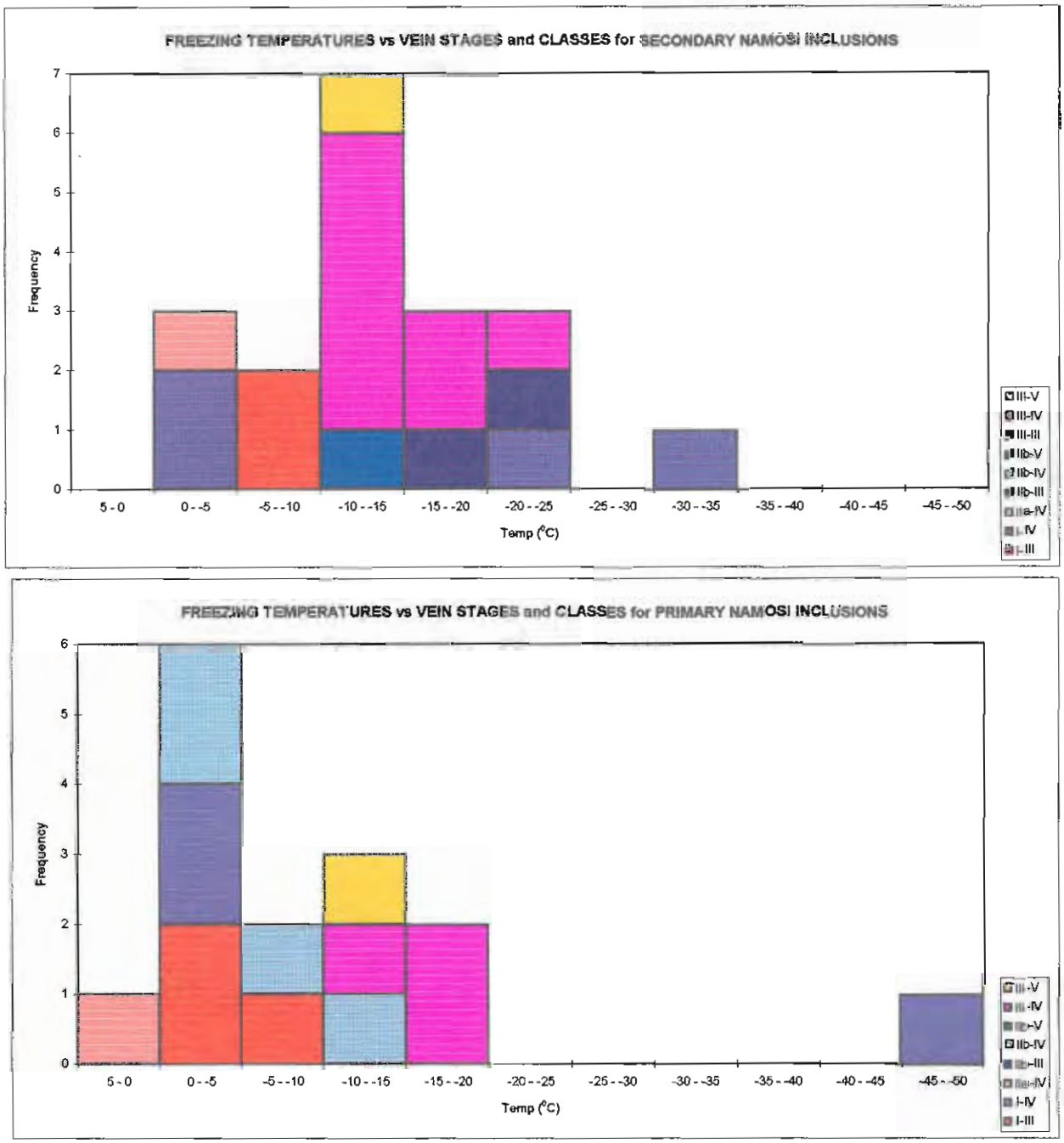


Figure 5.2a Frequency distribution for freezing points vs class and stage for primary and secondary Waisoi inclusions.

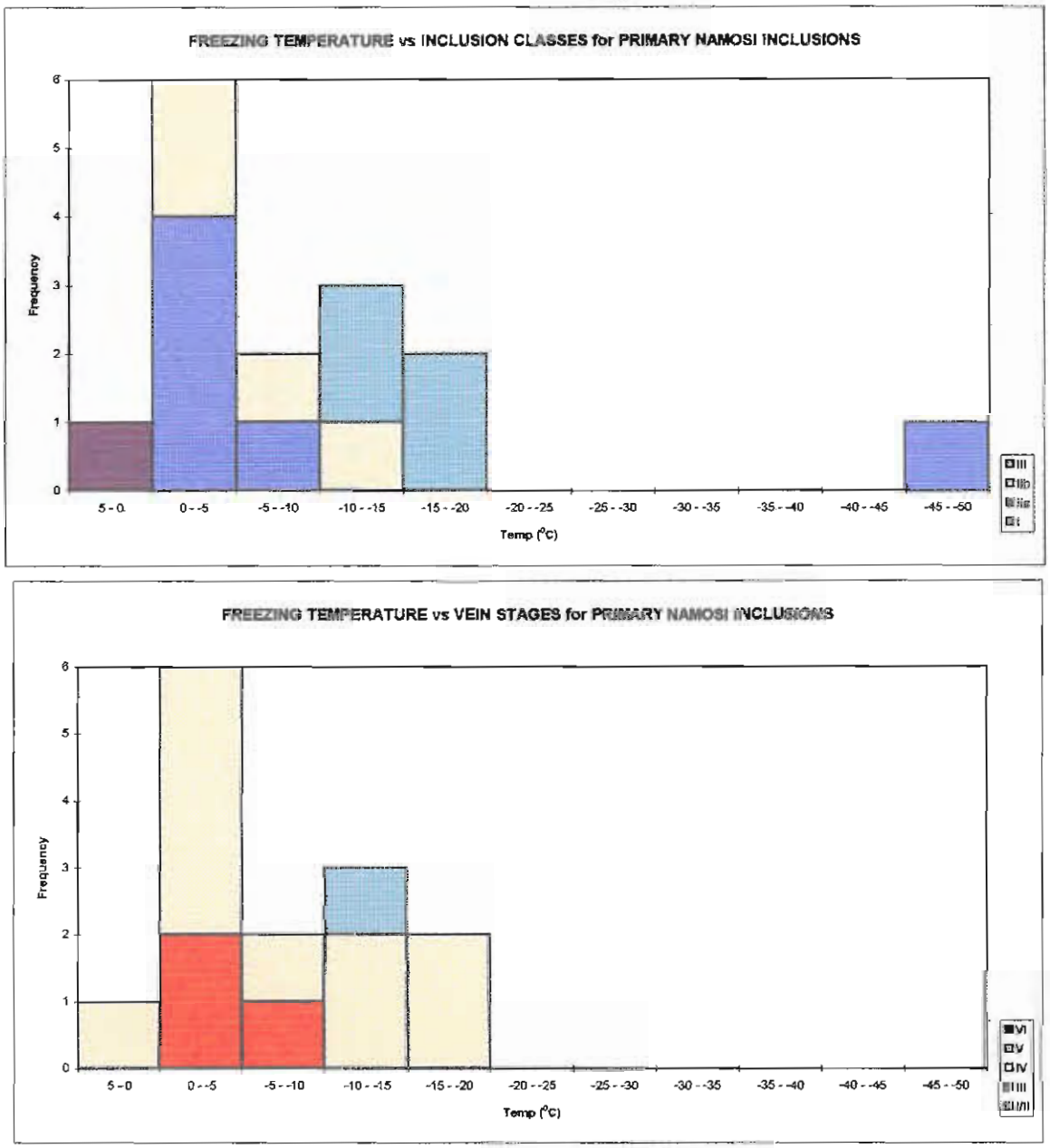


Figure 5.2b Frequency distribution for freezing points for Waisoi primary inclusions.

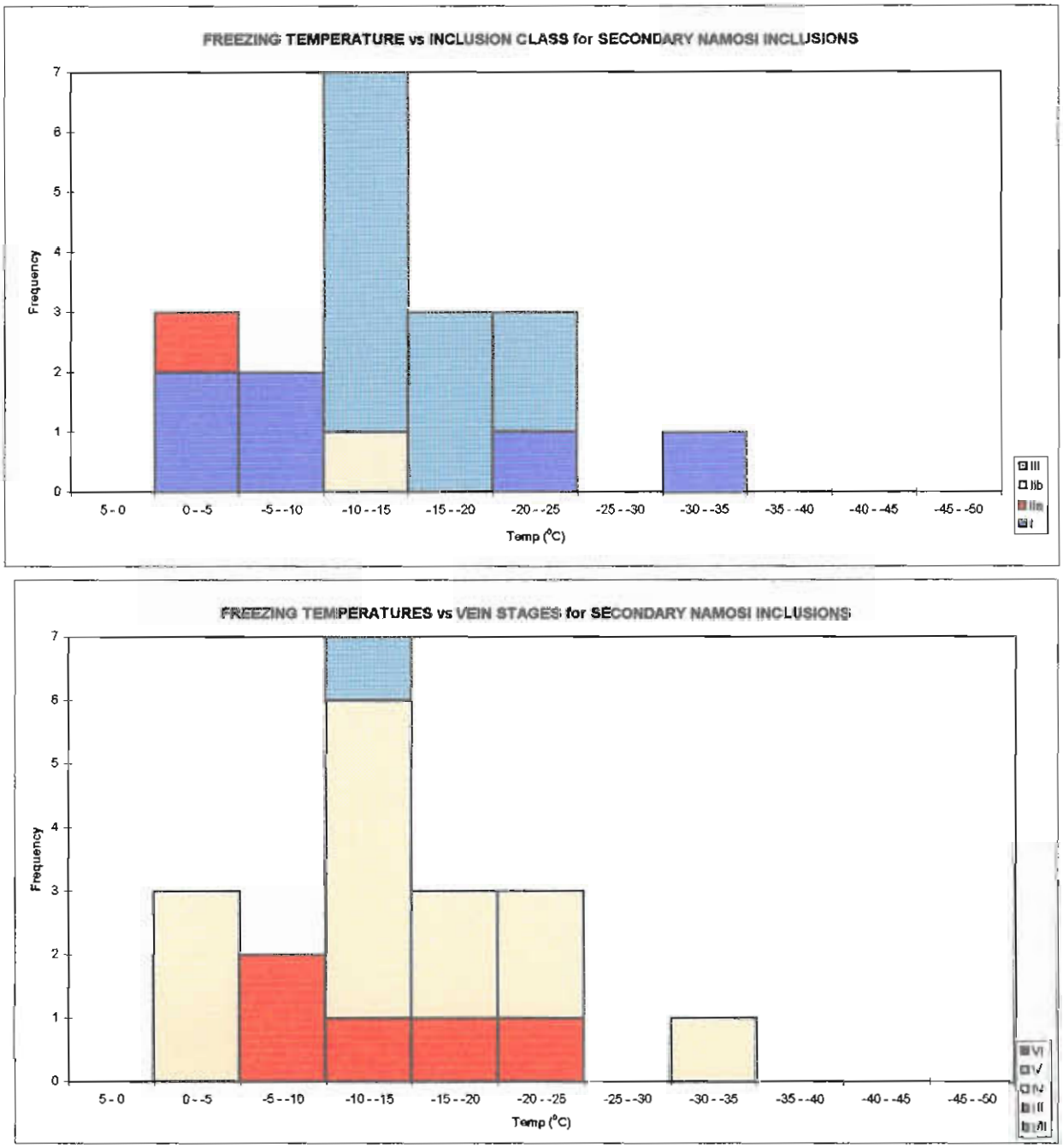


Figure 5.2c Frequency distribution for freezing points for Waisoi secondary inclusions.

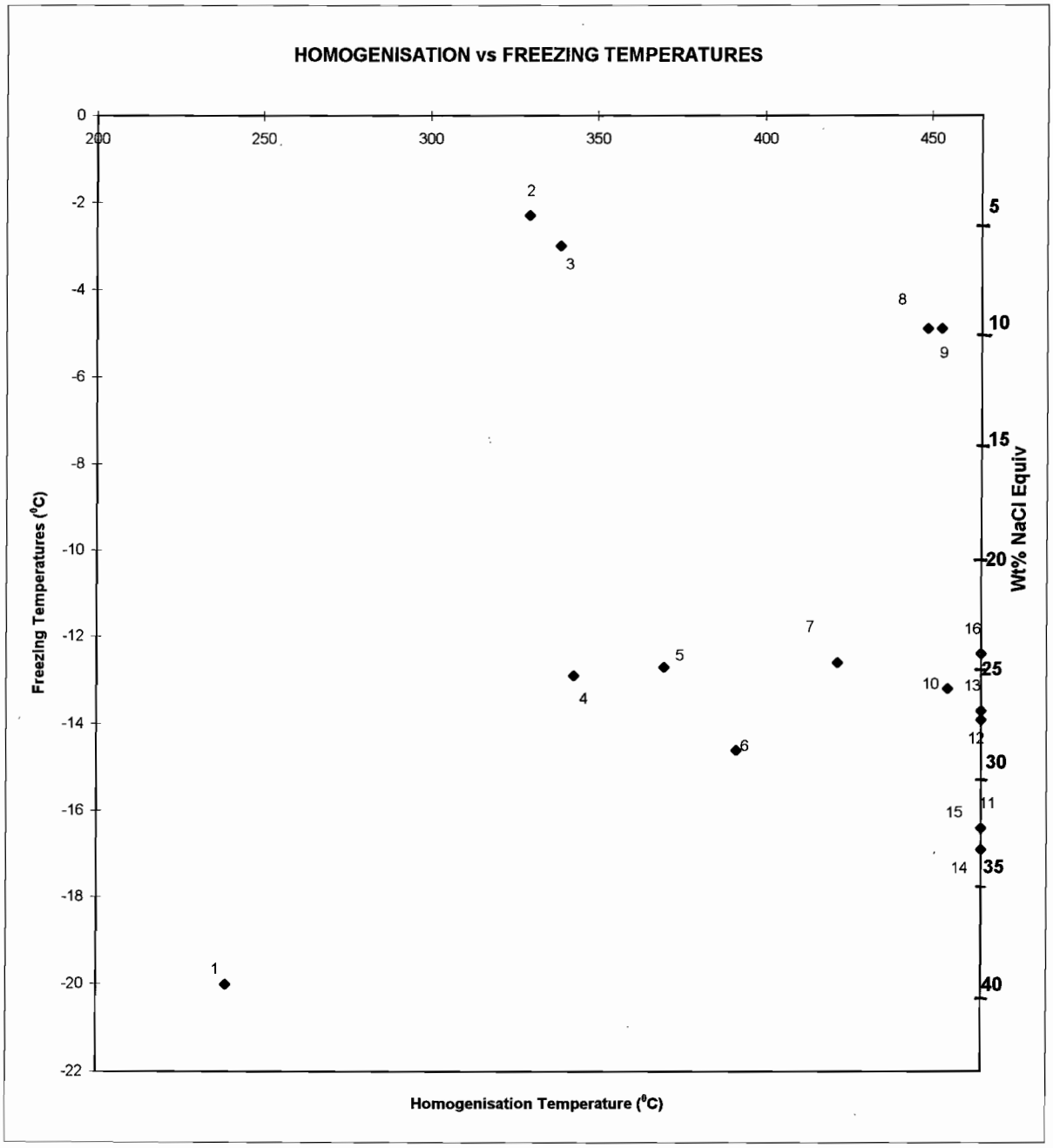
-2.3 to -4.9 ^{0}C, -6.6 to -6.8 ^{0}C, and -14.6 to -20.0 ^{0}C, corresponding to salinities of 3.9 to 8.4 wt.% NaCl equivalent, 11.6 to 12.0 wt.% NaCl equivalent, and 18.3 to 22.4 wt.% NaCl equivalent, respectively. The halite-saturated fluid inclusions had groupings of ice melting temperatures of -12.4 to -14.2 ^{0}C, -16.1 to -16.9 ^{0}C, and -21.2 to -24.2 ^{0}C corresponding to salinities of 22.2 to 25.7 wt.% NaCl equivalent, 29.5 to 32.3 wt.% NaCl equivalent, 40.5 to 47.7 wt.% NaCl equivalent, respectively. Such salinities and ranges of salinities are typical of porphyry-style mineralisation systems (Cooke and Bloom, 1990) with both early, high salinity, magmatic fluids and later, lower salinity, mixed (magmatic and meteoric) fluids (Kusakabe, et.al., 1989; Masterson & Kyle, 1984).

Dissolved gases may contribute a small amount to the depression of freezing points of the inclusions. The presence of dissolved gases was indicated by the observation of the formation of clathrate in rare inclusions.

Few inclusions were suitable to give both heating (homogenisation) and freezing (melting) temperatures. However, the few paired results (Figure 5.3) show there is a general relationship between the pressure corrected homogenisation temperatures and the ice melting temperatures. Inclusions with higher homogenisation temperatures have higher salinities. This suggests the earlier, higher temperature fluids were higher salinity, magmatic fluids.

The salinities of the early stages of porphyry-style veins tend to have high salinities of 20 to 47.7 wt.% NaCl equivalent. Fluid inclusions without daughter minerals, even in the early stage veins, have salinities of 11.6 to 12.0 wt.% NaCl equivalent. Late stage veins tend to have fluid inclusions with lower salinities (<10 wt.% NaCl equivalent).

However, in some of the samples with fluid inclusions having the higher homogenisation temperatures (Wn2/193.1) and higher salinities, there are fluid inclusion populations with the lower homogenisation temperatures and the lowest salinities. Since these inclusions are secondary, they occur in separate areas of the sample, and there is no evidence of boiling, it is probable that the two inclusion populations represent different phases of inclusion trapping. The



	SAMPLE NOS
1	109594
2	WSD212@80.1
3	WSD238@137.8
4	WSD228@107.4
5	WSD214@232.5
6	WSD228@117.4
7	WN2@193.1
8	WSD238@137.8
9	WSD238@137.8
10	WSD238@137.8(H)
11	WSD238@137.8(H)
12	WSD228@117.4
13	WSD228@117.4
14	WN2@193.1
15	WN2@193.1
16	WN2@193.1

Figure 5.3 Homogenisation and freezing temperature relationships.

lower salinity inclusions were probably trapped during a later stage decline in thermal activity associated with mixing of meteoric fluids.

5.1.4 Fluid Inclusion Summary

The study of fluid inclusions in the veins from the Waisoi porphyry copper/gold alteration and mineralisation has shown typical porphyry system characteristics. Most of the inclusions were small (commonly < 15 microns), liquid-rich, secondary inclusions in quartz grains. Many inclusions were two phase, with co-existing liquid and vapour phases at room temperature, and many also contained daughter minerals (commonly hematite, halite and sylvanite(?)). Rare primary inclusions existed but tended to be necked, with possible phase separation having occurred.

Some samples showed populations of vapour-rich inclusions co-existing with populations of liquid-rich inclusions, which suggested phase separation had occurred, probably in the form of boiling.

Fluid inclusions in individual samples had a wide range of homogenisation temperatures, particularly in the early stage veins where ranges of +/- 80^{0}C were noted. Samples of the later vein stages showed more restricted variations in fluid inclusion homogenisation temperatures (+/- 40^{0}C). This has been noted in many other porphyry deposits (Bodnar & Beane, 1980; Roedder, 1984; Losada-Calderon, 1992). This may be due to fluid inclusions being from different vein stages, leakage (during heating and during successive deformation and/or vein stages), heterogeneous trapping of both vapour- and liquid-rich phases during phase separation, and some fluctuations in pressure and/or salinity at the time of entrapment.

The microthermometry heating and freezing measurements and the salinity calculations suggested that at least three fluid inclusion populations occurred in the Waisoi porphyry system. These indicated that at least four fluid types had passed throught the system, and these had characteristics of:

- a very high temperature fluid (>480^{0}C) with high salinities (+45 wt.% NaCl equivalent),

- a high temperature, high salinity fluid (>380^{0}C, +45 wt.% NaCl equivalent),
- a low temperature, lower salinity fluid (<300^{0}C, 10 wt.% NaCl equivalent),
- a second lower temperature, low salinity fluid (200^{0}C, <10 wt.% NaCl equivalent).

Although there are significant homogenisation temperatures ranges in each of the vein stages, there is an overall decrease in temperatures from the early to later stages.

It is suggested the higher temperature fluid may represent magmatic fluids, while the low temperature fluid may represent a strong influence of meteoric fluids. Several other fluids may also have been involved in the Waisoi mineralisation and these may have been caused by mixing of magmatic and meteoric fluids (Sirnmons,1991; Simmons & Browne, 1990; Smith & Kesler, 1985; Wilson, et.al., 1980). Mixing of magmatic and meteoric fluids may also be an explanation for the co-existence of low and high density fluid phases, if magmatic gas flows upwards and mixes with ground waters (Cooke & Bloom, 1990). However, phase-separation is most likely to be as a result of the boiling of magmatic fluids (Losada-Calderon, 1992).

The presence of the daughter minerals indicates highly saline fluids were present in the formation of the veins. However, the presence of hematite is not necessarily indicative of oxidising formational fluids, as the hematite may have formed due to hydrogen diffusion (J. Walshe, pers. comm., 1995).

The introduction of chalcopyrite and bornite is related to high salinity, high temperature fluids early in the evolution of the porphyry system. The decrease in the salinity (as well as temperature) of the fluids in the later stages of the porphyry system evolution can be interpreted as mixing with low salinity water in a waning magmatic-hydrothermal system. However, fluid inclusion data alone are not sufficient to determine the source of the low salinity, low temperature fluids.

In conclusion the study of fluid inclusions, combined with the study of the various stages of veining (mineralisation and alteration paragenesis), has shown that the early stages of porphyry mineralisation at Waisoi was characterised by high salinity (10 - 15 wt.% NaCl equivalent), high temperature (+450^{0}C) fluids, probably derived from a crystallising magma. These characteristics are shown by the early stage quartz veins (cut by later copper-rich quartz veins). As the system evolved hypersaline (20 - +45 wt.% NaCl equivalent), high temperature (+450^{0}C) fluids were exsolved. These fluids contained significant amounts of copper, which may have been precipitated when the fluid was mixing with lower salinity (10 wt.% NaCl equivalent), lower temperature (<300^{0}C) fluids. The later stages of the evolution of the porphyry system is characterised by lower salinity (<10 wt.% NaCl equivalent), lower temperature (200^{0}C) fluids, which may represent pulses of magmatic - hydrothermal fluids (sourced from the Waisoi intrusives) mixing with ground waters. A later (carbonate-rich) stage of fluid movement may have been related to a dominantly meteoric sourced fluids.

The alteration and mineralisation at Waisoi is not a single event but rather a series of events. These have been recorded in the fluid inclusion occurrence by the presence of abundant stages of secondary inclusions, particularly in the veins related to the early stages of the evolution of the porphyry system. The later veins have only one or two stages of fluid inclusion development.

5.2 GEOCHEMISTRY

During the 1965 to 1994 period there have been a variety of geochemical techniques used to determine the size and grade of the Waisoi porphyry-related mineralisation. These have included drainage, soil, rock and drill core analyses as well as minor whole rock and trace element geochemistry. A short review of the results of the various geochemical techniques follows.

5.2.1 Soil/Drainage/Rock-chip Geochemistry

Several drainage and soil geochemistry programmes have been completed in, and around, the Waisoi area. The various surveys by several companies showed some differences.

Rock-chip sampling has not been significant at Waisoi due to the lack of significant fresh outcrop.

5.2.1.1 Drainage Geochemistry

Drainage geochemistry (-80#) was completed over parts of the Namosi area by Central Mining Finance (CMF), AMAX (Leggo, 1977), Australian Anglo American (AAA) Limited (Ellis, 1991) and Placer (Ellis & Jay,1991).

The initial CMF work (assayed for Cu, Pb, Zn, Co, Ni and cold extractable Cu) showed anomalous areas around Waisoi West (to 1400ppm Cu and >100ppm CxCu) and Waisoi East (to 1000ppm Cu), with a background of around 100ppm Cu (below detection for CxCu) elsewhere in the area (Figure 5.4). Drainages from the Waisoi North area were also anomalous (320 to 900 ppm Cu and +40ppm xCu).

Similarly, the work by AMAX (analysed for Cu, Pb, Zn, Mo and cold extractable Cu, with the pH of the stream water at the sample point also being measured) confirmed the CMF results but with lower absolute values (Figure 5.5). The AMAX work failed to show the Wainabama area to be anomalous (Figure 5.6) and the Waisoi North area was not recognised, even though the samples contained anomalous Cu values (Leggo, 1977). All streams in the Waisoi area contained acid water, with a pH in the range of 4.1 to 6.6. There was no

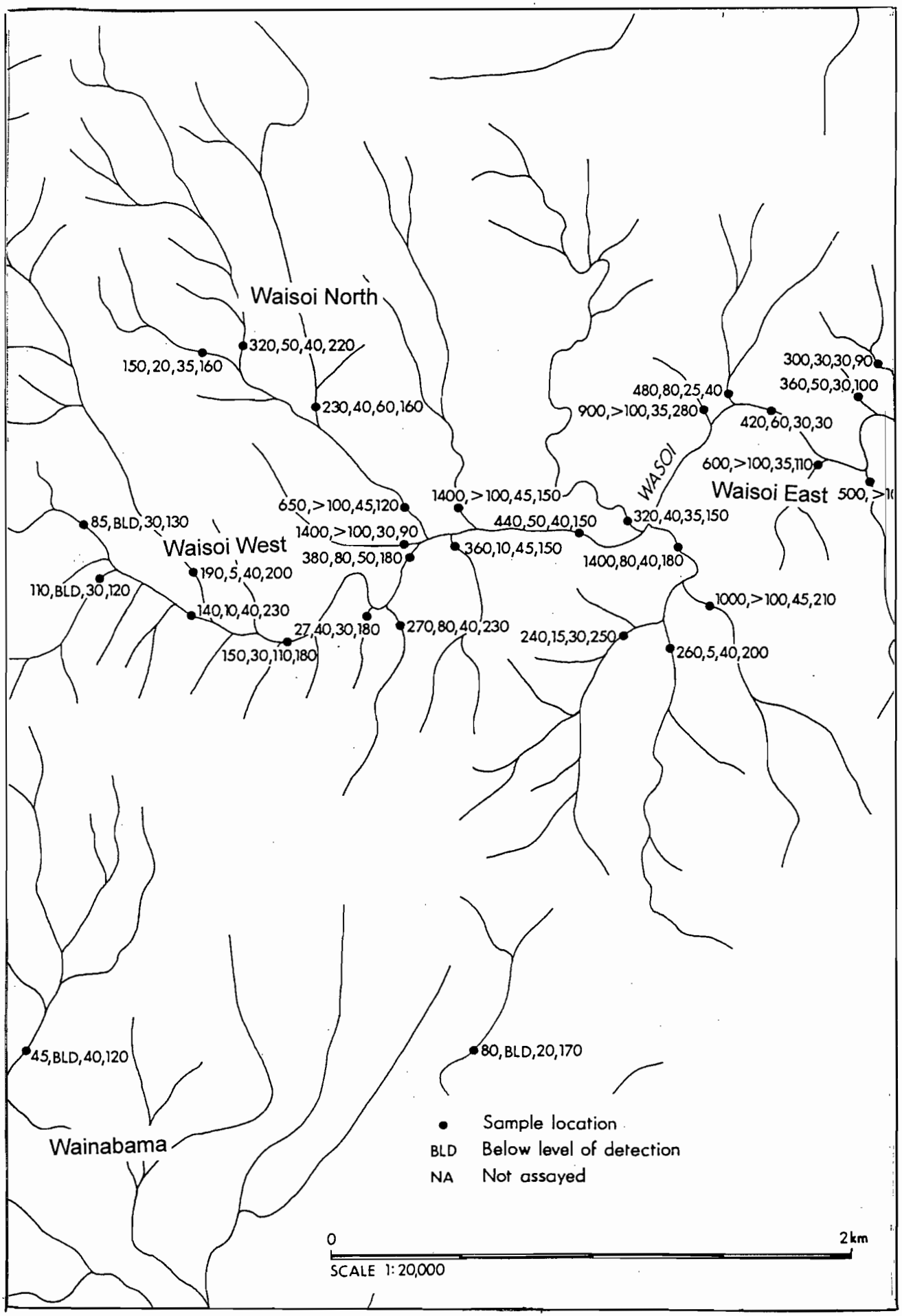


Figure 5.4 CMF Waisoi drainage geochemistry.

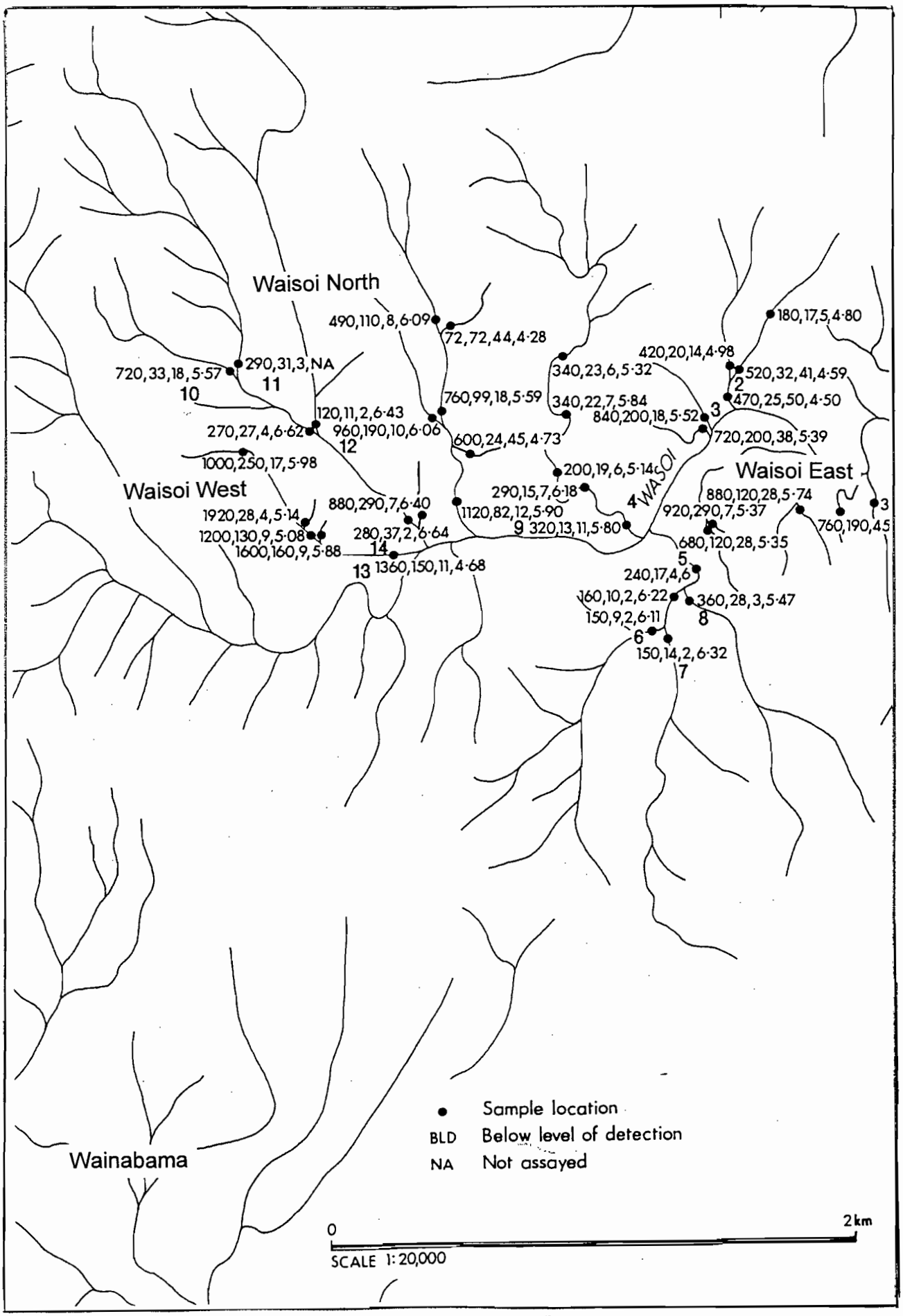


Figure 5.5 AMAX Waisoi drainage geochemistry.

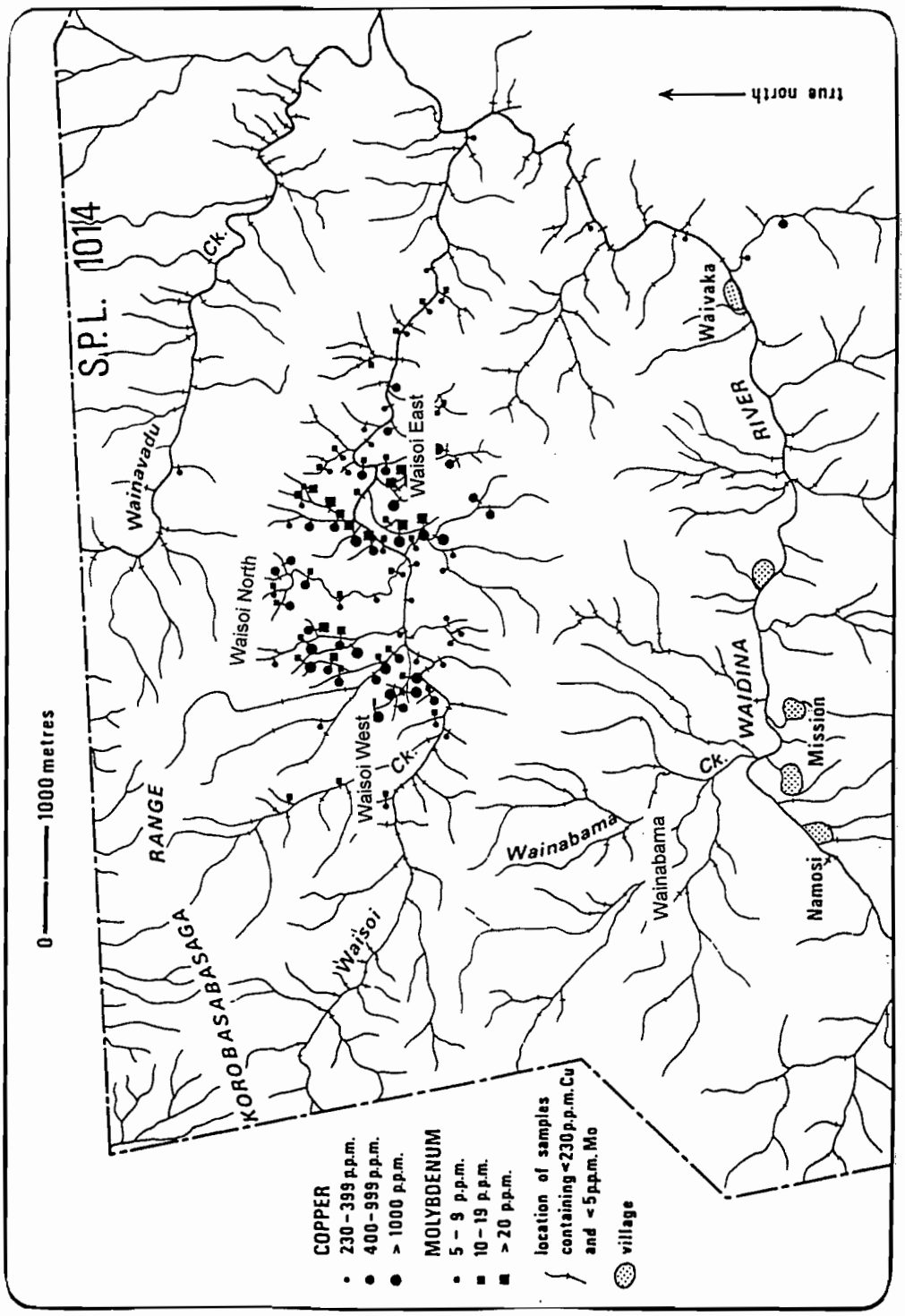


Figure 5.6 AMAX regional drainage geochemistry.

significant difference in the pH for streams draining the mineralisation (possible less acid) and other streams, suggesting the pyrite in the broad propyllitically altered zone may be responsible for the acid conditions.

The AAA work (analysed for Cu, Pb, Zn, As, Sb, Mo, Te, Ag, Ba and Au) showed similar results (Figure 5.7) to the AMAX work (Ellis,1991). Again anomalous Cu values in the Waisoi North area were not recognised as significant (Ellis, 1991). Also weak anomalies were noted in the Wainabama area (Figure 5.7) confirming the early CMF results.

The Placer work involved selected drainages being resampled and the results compared to the earlier work. Results showed the CMF and AAA Cu results were able to be reproduced fairly accurately (Table 5.3) and confirmed the Waisoi North area required further investigations (follow-up mapping located the main mineralised zone prior to drilling - see above).

Most other elements like Au, Mo, Pb, As and Sb showed variable values but with no distinct pattern.

In summary the -80# drainage Cu geochemistry effectively defined the porphyry copper mineralisation around the Namosi area, in particular the Waisoi East, Waisoi West and Waisoi North mineralised zones.

5.2.1.2 Soil Geochemistry

The Waisoi area has been soil sampled using ridge and spur sampling, grid based soil sampling and by means of pits (Ellis,1991). Results for Cu analyses from the early CMF ridge and spur sampling was confirmed by the AMAX ridge and spur soil sampling techniques (Figure 5.8). Grid based Cu soil sampling results (Figure 5.9) confirmed the ridge and spur sampling and the pit sampling, and showed agreement with the results of the drilling programmes (Leggo, 1977), including the location of the Waisoi North mineralisation.

Interestingly, the Cu values obtained in the soil sampling programmes were significantly lower than the Cu values in the underlying rocks, showing that Cu was being leached-out rather than undergoing supergene enrichment.

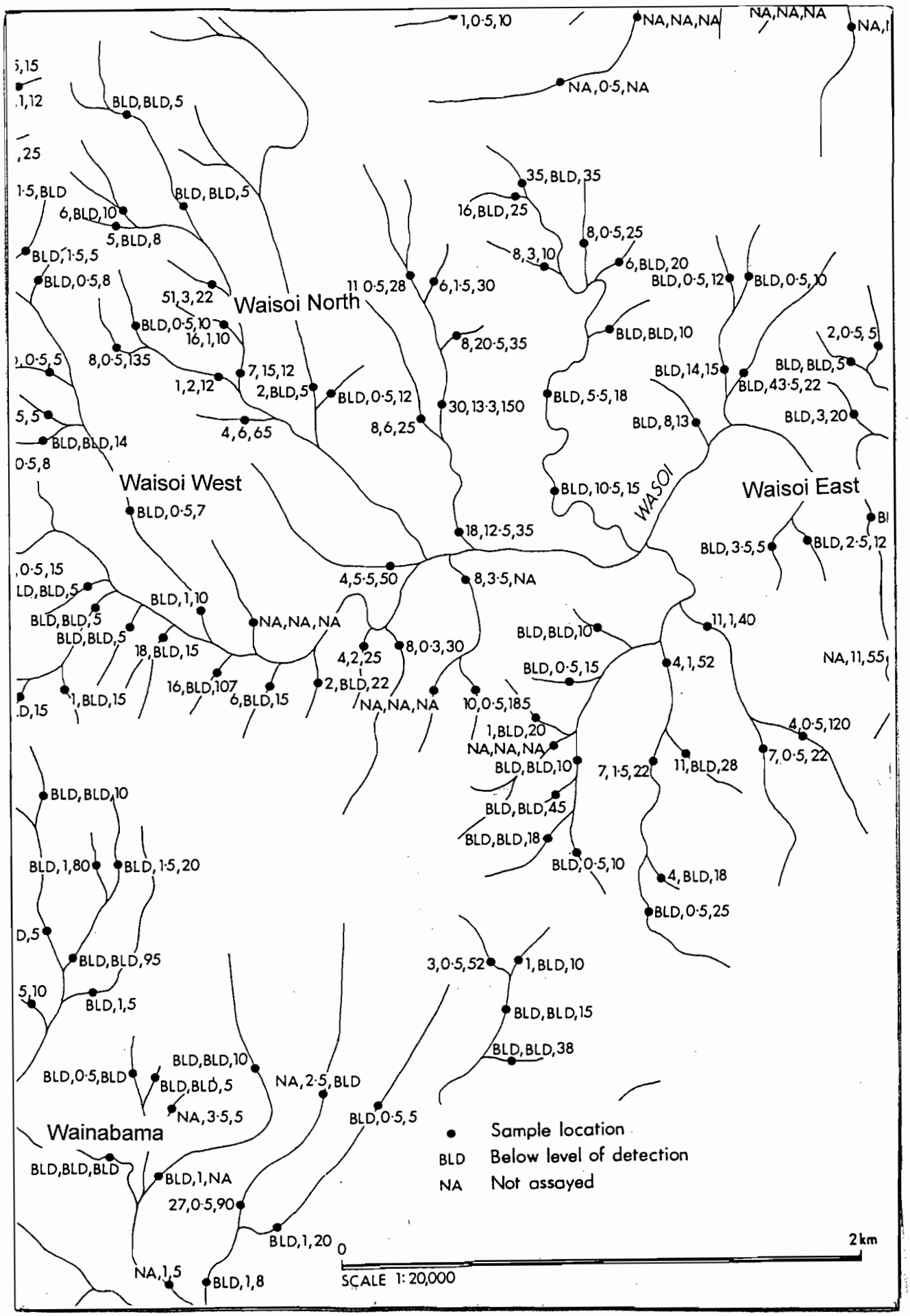


Figure 5.7 AAA Waisoi drainage geochemistry.

TABLE 5.3 Comparison of drainage geochemistry results

	Cu				Cx Cu		Mo		Pb	
	AMAX	CMF	AAA	PEL	AMAX	CMF	AMAX	AAA	CMF	AAA
1	380	500	405	485	45	100	3	12	30	x
2	470	480			25	80	50		25	
3	840	900	265		200	>100	18	8	35	x
4	320	320		315	13	40	11		35	
5	240	460		435	17	80	4		40	
6	150	240		230	9	15	2		30	
7	150	260	215	255	14	5	2	1	40	4
8	360	1000	590	995	28	>100	3	1	45	11
9	1120	1400	1100	1390	82	>100	12	12.5	45	18
10	720	150	320	165	33	20	18	2	35	1
11	290	320	160		31	50	3	1.5	40	7
12	120	230	78	220	10	40	2	0.5	60	2
13	1360	1400	1120	1385	150	>100	11	5.5	30	4
14	280	650		660	37	>100	2		45	

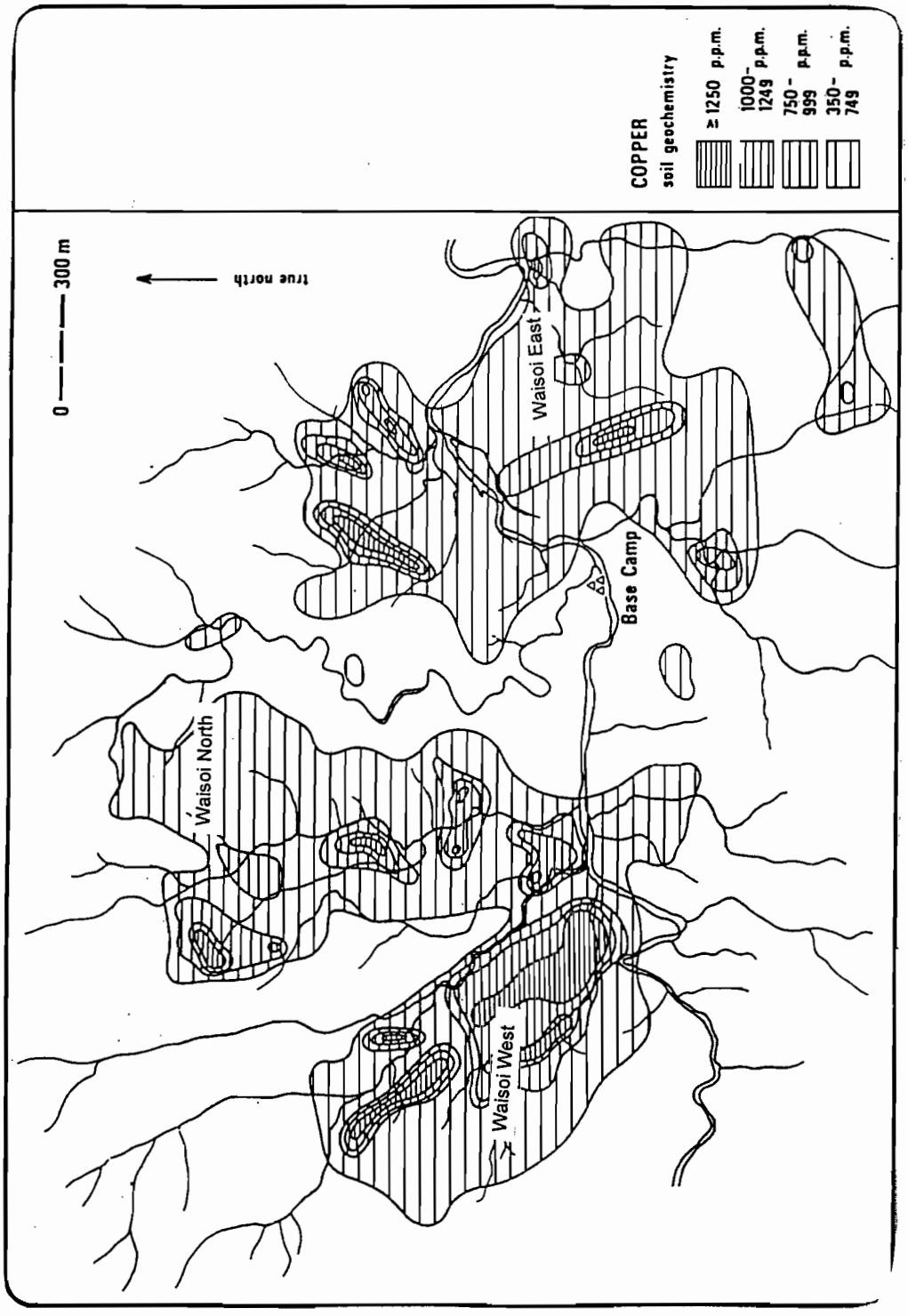


Figure 5.8 AMAX Waisoi ridge and spur soil Cu geochemistry.

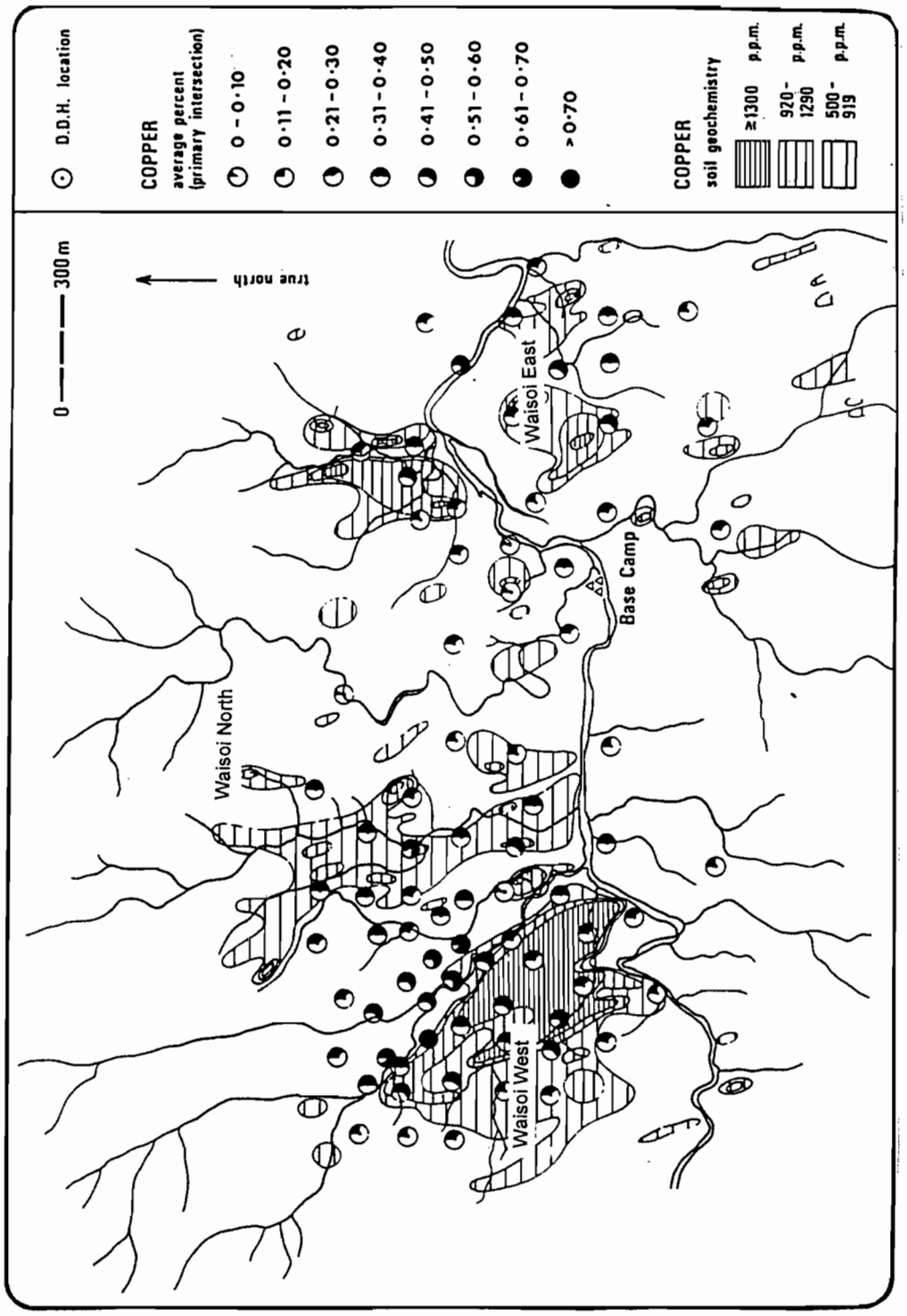


Figure 5.9 AMAX Waisoi grid soil Cu geochemistry.

The Mo distribution (Figure 5.10) showed the Waisoi East mineralisation was Mo-enriched (Leggo, 1977). This was confirmed by the drilling, although the recent drilling has shown the northwestern part of Waisoi West contains elevated Mo. This was indicated from the soil Mo distribution (Figure 5.10).

The Au soil distribution (Figure 5.11) was spotty and erratic, but the Zn distribution (Figure 5.12) tended to suggest the Zn was peripheral to the Cu mineralisation. Other elements showed no significant anomalies.

In summary, soil sampling was not a good technique in the Waisoi region as it did not enhance the drainage geochemistry results. This was mainly due to much of the Waisoi area being covered by land-slips and/or gravel terraces, and the acid waters tended to leach Cu from the soil profile.

5.2.2 Wholerock Geochemistry

The only wholerock geochemistry completed on rocks from Waisoi is from ten samples collected early in this current study to determine the affinities of the volcanic units (Table 5.4). This data suggests that the Wainimala Agglomerate are basaltic andesites with Ti/Zr values in excess of 100, SiO_2 contents of 50 to 55 percent and Fe_2O_3 contents of 10 to 15 percent (Figure 5.13).

Using the iron-enrichment pattern conclusions used by Gill (1987), the Wainimala Agglomerate and Namosi Andesite can be distinguished with FeO/MgO versus SiO_2 plots (Figure 5.13). The Namosi Andesite samples all plot in the calc-alkaline field, while the Wainimala Agglomerate samples plot in the island arc tholeiite field. Zr contents (Figure 5.13) also allow the Namosi Andesite and Wainimala Agglomerate to be distinguished, with the Namosi Andesite having significantly higher Zr (+80ppm) than the Wainimala Agglomerate (<60ppm).

The samples from the area logged as Basal Namosi Conglomerate (of uncertain sources) are dominated by material with a geochemical signature similar to the Namosi Andesite. The sample of Korobasabasga Pyroclastics shows affinities to the Wainimala Agglomerate and the island arc tholeiites.

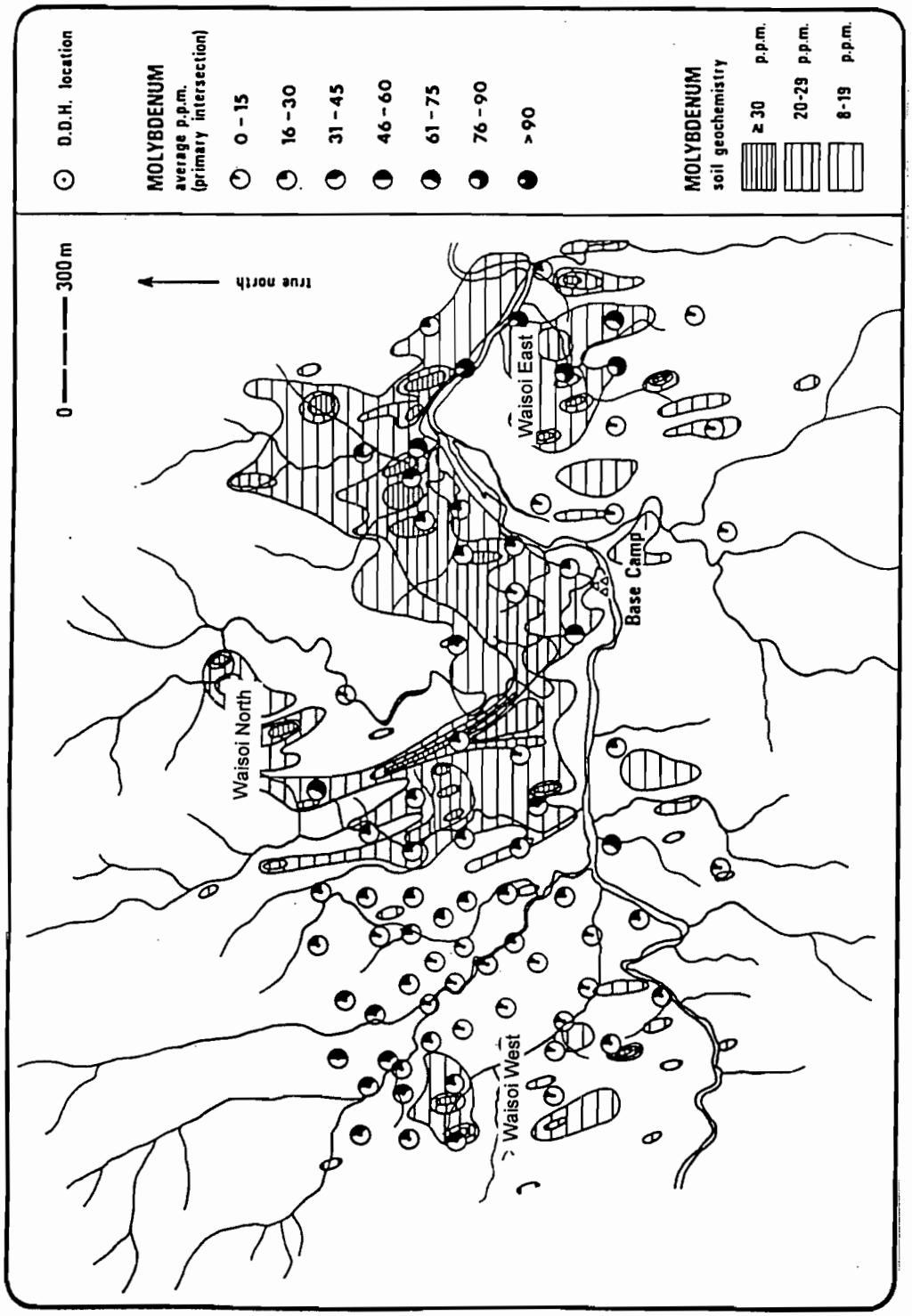


Figure 5.10 AMAX Waisoi grid soil Mo geochemistry.

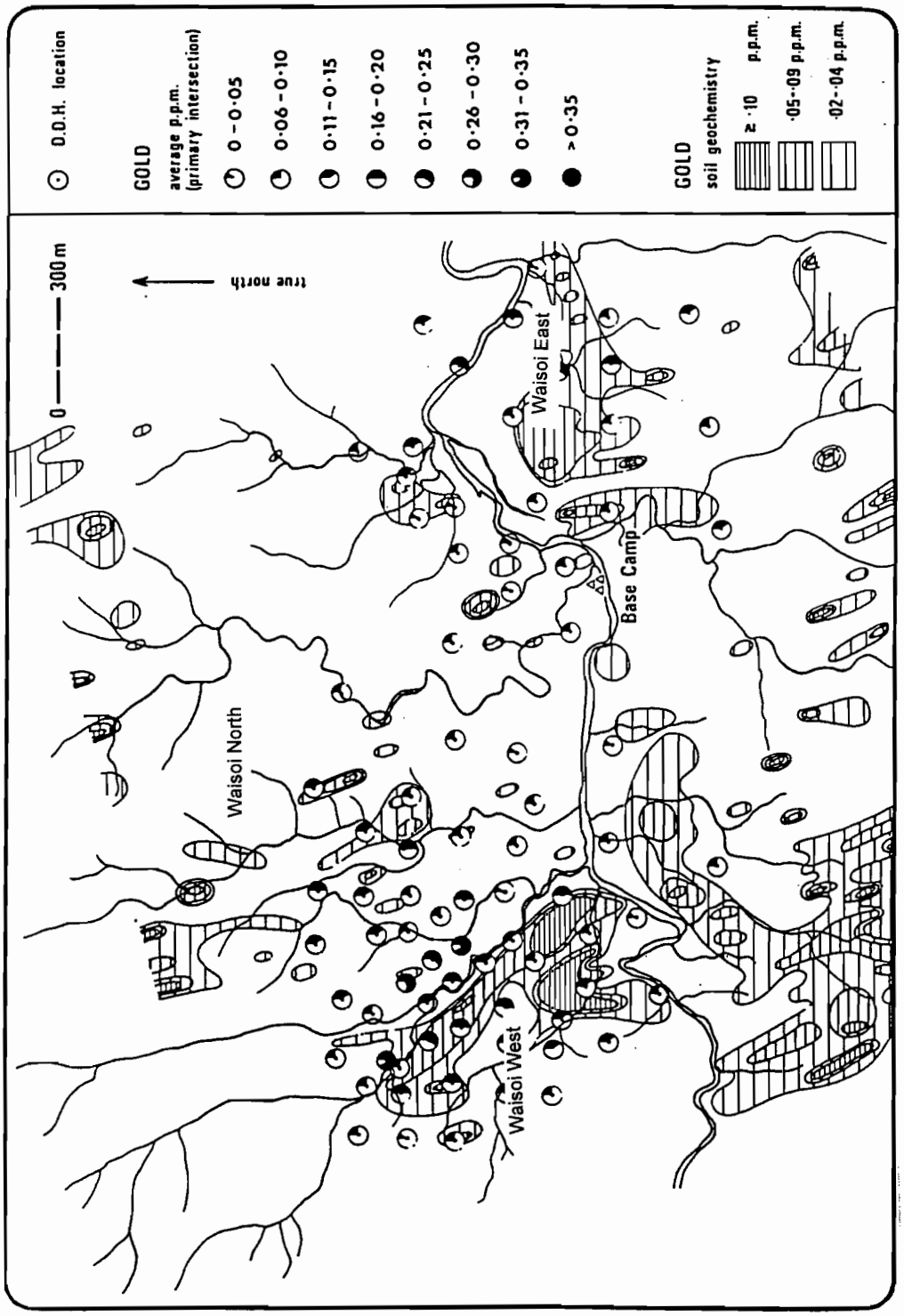


Figure 5.11 AMAX Waisoi grid soil Au geochemistry.

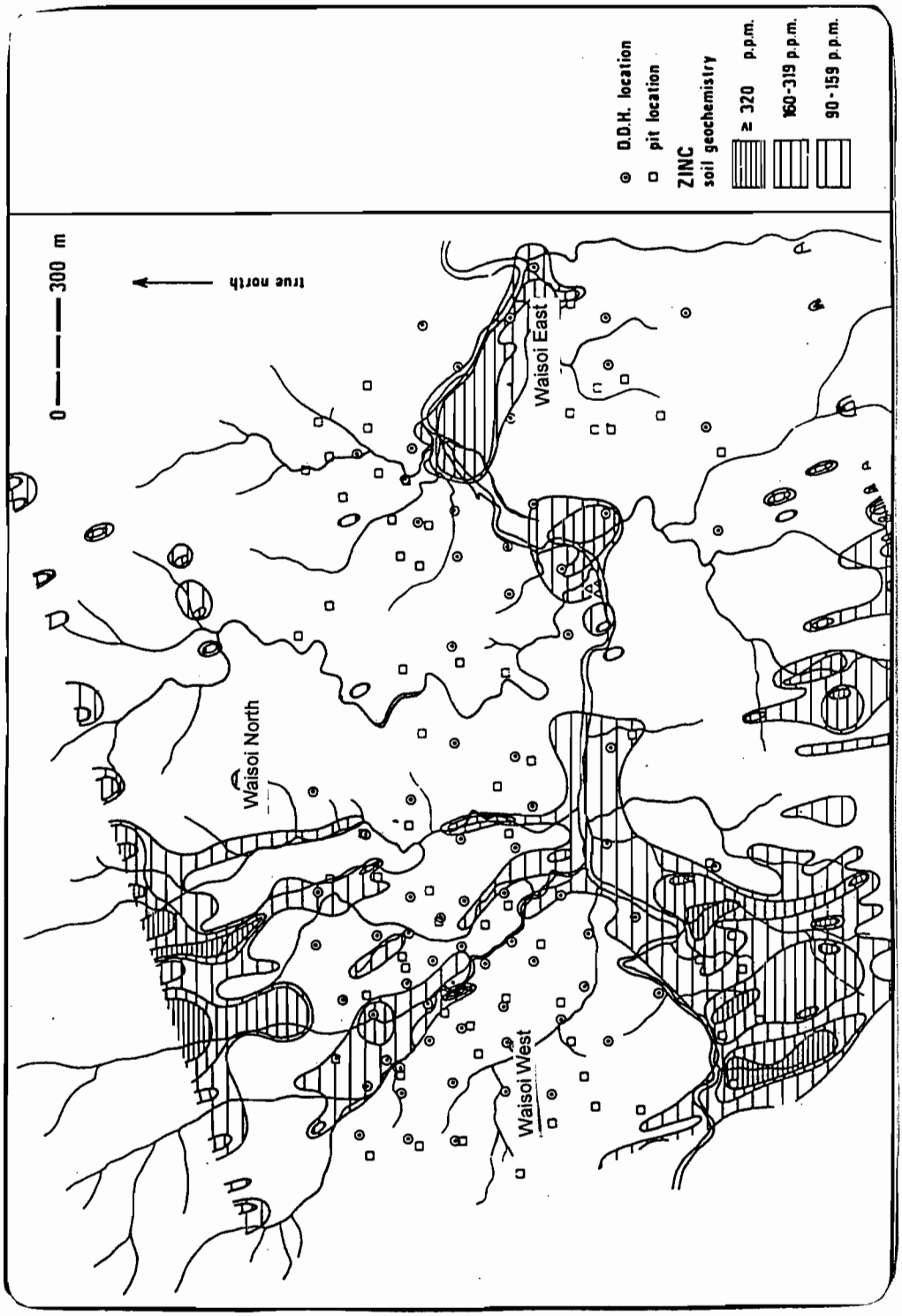


Figure 5.12 AMAX Waisoi grid soil Zn geochemistry.

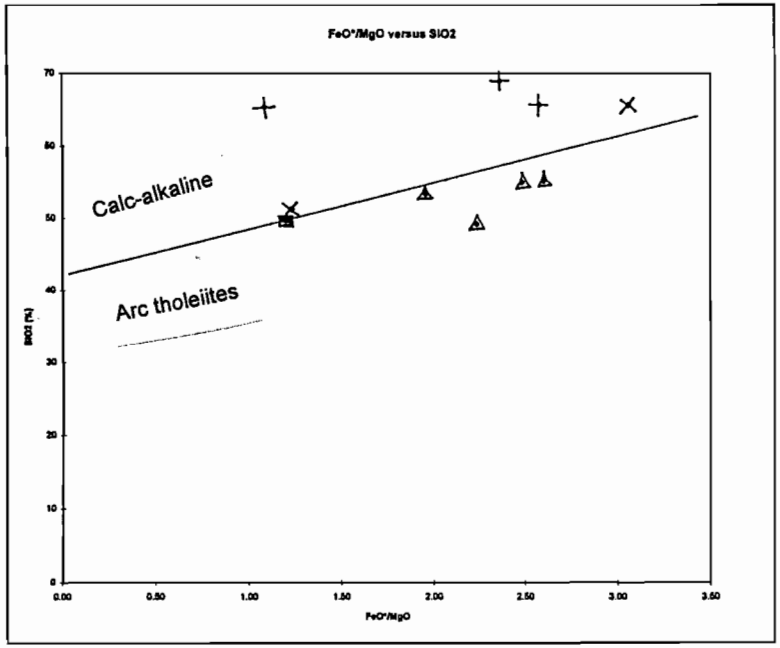
TABLE 5.4 Wholerock geochemistry of samples from the Waisoi area.

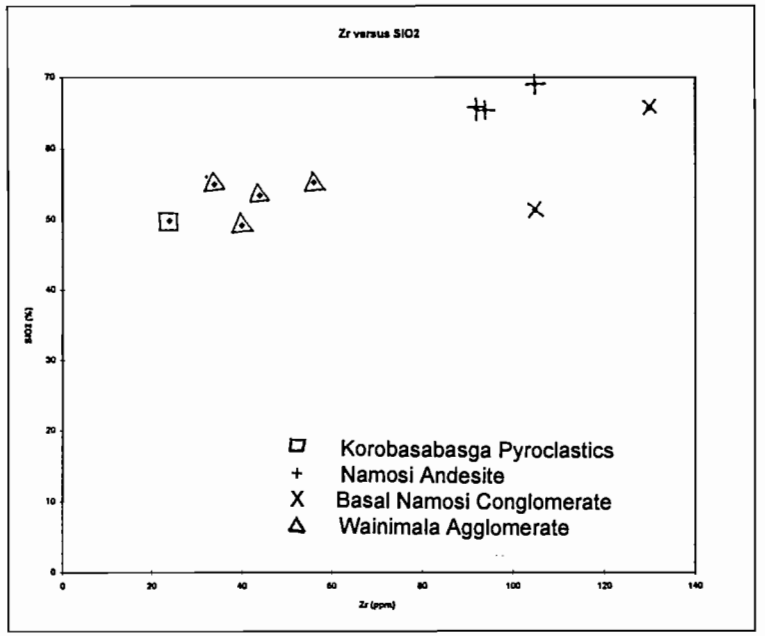
	Wainimala Agglomerate				WA?/BN?/NA?		Namosi Andesite			KB
	wsd81-193.0m	wsd164 247.1m	wsd212 318.6m	wsd212 330.5m	wsd50-222.7m	Namosi Gap-W	wsd50-100.1m	wsd81-97.0m	wsd164 145.3	Namosi Gap-W
SiO_2 (%)	55.2	49.2	55.0	53.4	51.3	65.7	65.4	65.7	69.0	49.8
TiO_2 (%)	1.36	0.81	0.81	0.78	0.84	0.97	0.81	0.8	0.77	0.71
Al_2O_3 (%)	26.2	20.7	17.5	17.8	19.6	15.4	17.5	16.6	18.5	18.4
Fe_2O_3 (%)	9.32	14.3	11.3	10.5	9.22	6.67	3.96	7.3	4.79	9.14
MnO (%)	0.15	0.09	0.06	0.09	0.14	0.21	0.02	0.04	0.01	0.16
MgO (%)	3.58	6.4	4.55	5.37	7.49	2.18	3.65	2.83	2.03	7.63
CaO (%)	3.48	5.75	6.07	5.99	5.88	2.73	3.2	3.74	0.06	9.84
Na_2O (%)	0.17	2.32	3.40	3.64	3.39	4.34	5.02	1.96	0.51	3.89
K_2O (%)	0.37	0.24	1.03	1.02	1.97	1.58	0.27	0.88	4.29	0.37
P_2O_5 (%)	0.16	0.13	0.13	0.13	0.11	0.26	0.16	0.17	0.01	0.06
LOI (%)	15.4	5.85	3.64	2.28	5.05	3.76	5.2	7.45	5.15	6.05
Zr (ppm)	56	40	34	44	105	130	94	92	105	24
As (ppm)	250	4	<2	2	6	<2	<2	<2	3	<2
Rb (ppm)	3	<2	20	19	32	14	<2	11	45	<2
Sr (ppm)	20	155	175	250	180	270	330	260	46	210
Nb (ppm)	<2	<2	2	<2	<2	<2	<2	<2	<2	<2
Y (ppm)	28	16	20	18	15	42	18	20	20	12
Pb (ppm)	15	38	12	12	46	40	70	52	30	26
Cu (ppm)	175	1220	590	270	2500	8	2900	56	2250	35
Zn (ppm)	50	22	17	16	36	90	18	26	5	48
Ag (ppm)	1	2	1	1	2	1	1	1	1	1
Cr (ppm)	50	70	<50	<50	120	30	90	<20	30	200
Ti/Zr	119	112	133	99	48	42	48	47	41	177

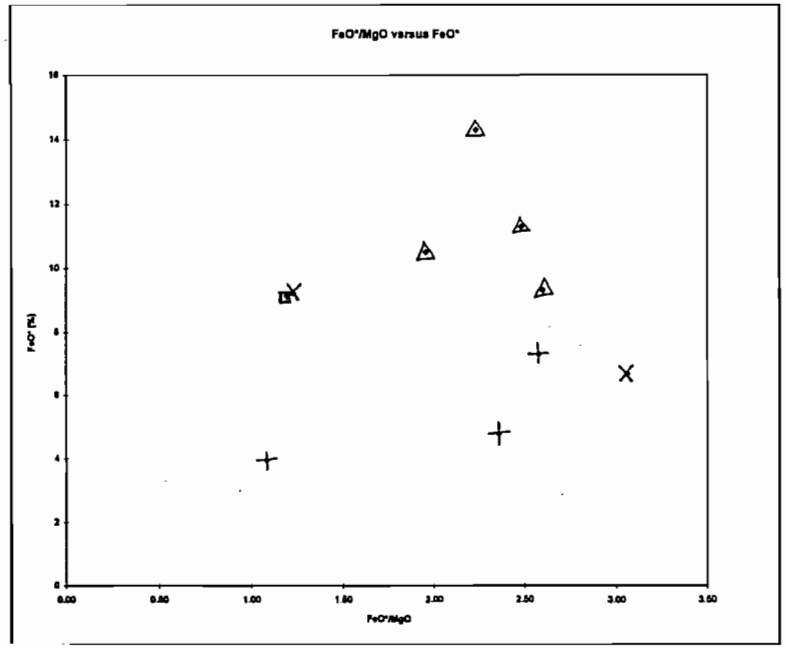
NA Namosi Andesite

BN Basal Namosi Conglomerate

WA Wainimala Agglomerate







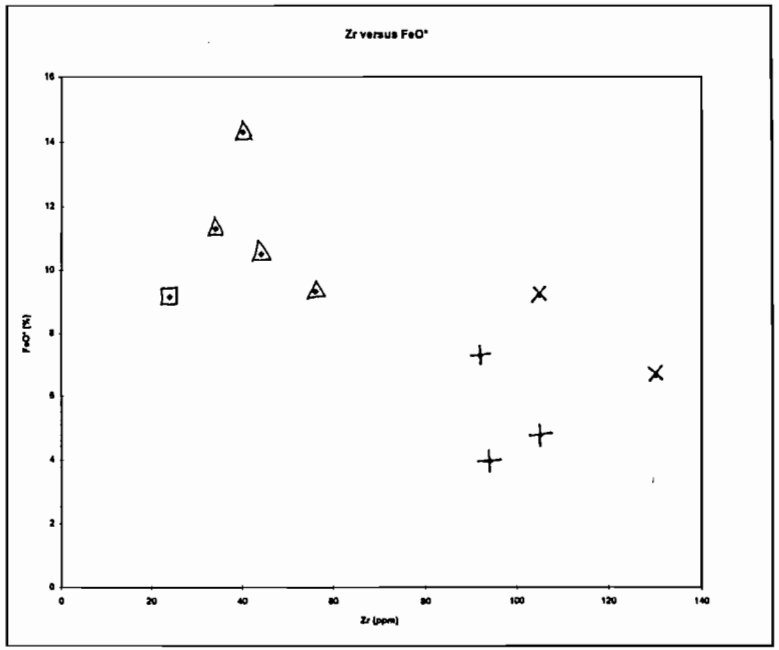


Figure 5.13 Scatter plots of elements from the wholerock geochemistry.

The high Fe_2O_3 of these samples reflects the high magnetite content. Two samples thought to be Wainimala Agglomerate fall outside these parameters and may actually be from Wainimala fragments from the Basal Namosi Conglomerate.

The Wainimala samples vary considerably from the Namosi Andesite samples which are dacitic and have SiO_2 contents of 65 to 70 percent, Ti/Zr values of 40 to 50 and Fe_2O_3 contents of around 5 percent.

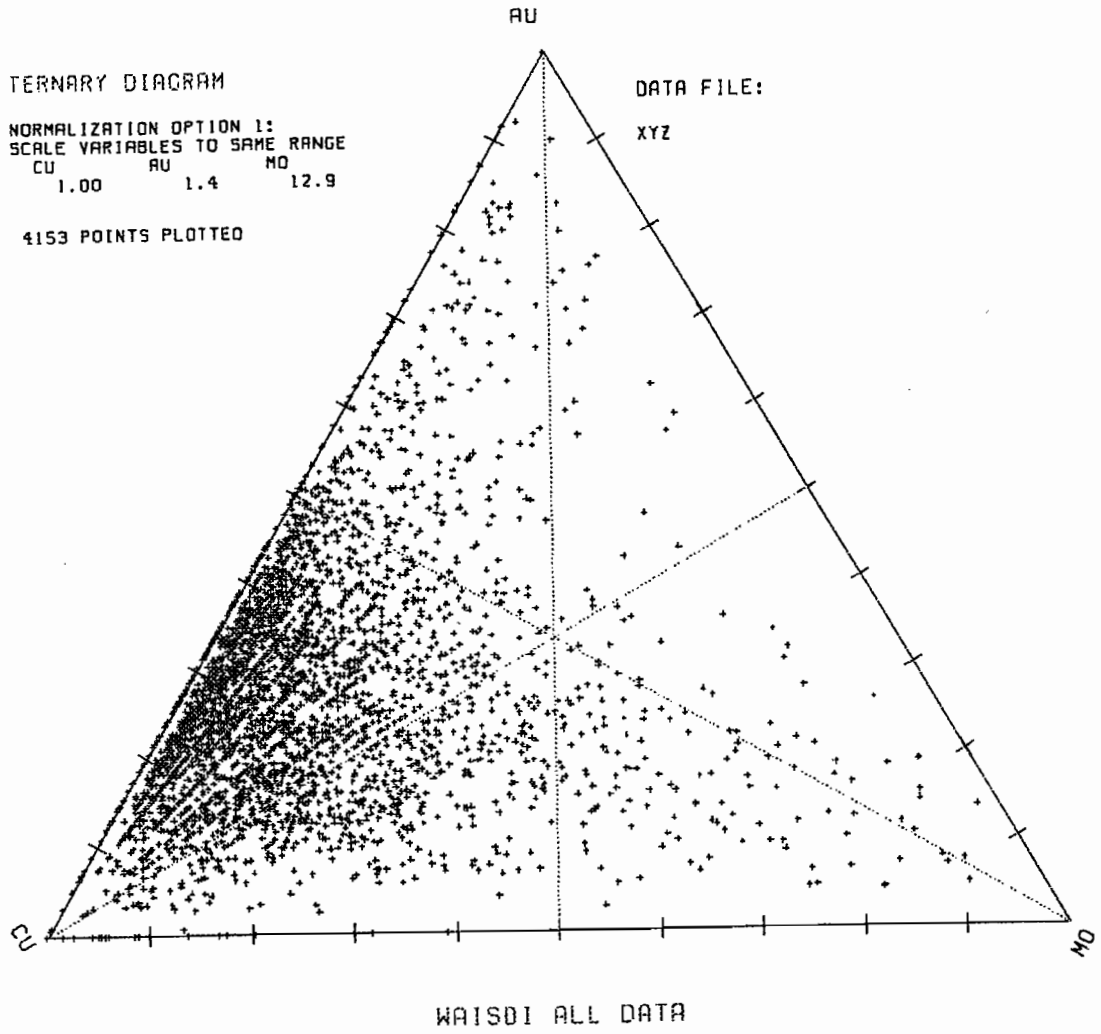
Na_2O, K_2O, CaO and MgO contents for Namosi Andesite and Wainimala Agglomerate samples vary considerably depending on the degree of alteration and mineralisation, and bear no relation to their original magma values.

The Korobasabasaga Pyroclastic sample is of an island arc tholeiitic composition with a low Zr value of 24 ppm and a correspondingly high Zr/Ti value of 177 (A. Crawford, pers.comm., 1993). This may be related to the Nakobalevu Basalt of SE Viti Levu and the Korobasaga Volcanics from the Lau Islands (Crawford, 1993).

5.2.3 Mineralisation Geochemistry

All drill core from the 1992 drill programme was assayed in 3m sample intervals for Cu, Au and Mo. The results of these analyses show the Waisoi porphyry deposits to be dominantly Cu with some Mo and only minor Au (Figure 5.14). The mean values for all samples from the 1992 drilling were 0.33% Cu, 22.5ppm Mo and 0.11ppm Au. Of these, both the Au and Cu showed good sample reproduction while Mo values were difficult to reproduce.

In general, the Cu distribution shown by the drill hole assays reflected the Cu mineralisation observed during the logging of the drill core. If minor (< 1%) chalcopyrite was visible (as either disseminated or vein/fracture controlled mineralisation) then Cu assays of 0. 2% Cu were recorded, while around 2% chalcopyrite gave assay results of around 0.6% Cu. If bornite was recorded in the drill logs then assay values were commonly above 0.6% Cu. Au, however, was never recorded in the drill logs and could not be visually associated with the assays. Molybdenum, when recorded in the logs, gave Mo assays of +100ppm.



Mean geochemical values.

Cu	0.33%
Au	0.11ppm
Mo	22.5ppm

Figure 5.14 Ternary diagram for Waisoi drill Cu-Mo-Au geochemistry.

Locally, variations between adjacent drill sample assays down each of the holes are significant, with adjacent samples varying as much as 1.2% Cu (0.1 to 1.3%). Similar variations occur between corresponding samples (same depths) in twinned (check) holes in both Waisoi West and Waisoi East. However, between twinned holes there is good agreement between the average copper grades of the respective holes. The agreement in average copper grades between adjacent twinned drillholes (averaged over wide drillhole length intervals) but with large variations in assays of adjacent samples, reflect the nature of copper distibution in the Waisoi porphyry deposit. Much of the mineralisation (particularly in the Wainimala Agglomerate) is controlled by fractures, which vary in intensity, density and width depending on the local rock properties and the stresses to which those rocks have been subjected.

The distribution of copper mineralisation (as described in Part 4) is reflected in the copper assays, although the assays show a more intricate pattern (probably controlled by local structures). Copper grades are linked closely with the porphyry intrusives, with most of the copper mineralisation being within 70m of the porphyry contact. The siliceous cores of the porphyries contain sub-economic copper grades, which gradually increase outwards towards the porphyry margins. Highest copper grades occur in the brecciated porphyry margins and surrounding shattered host rocks (Figures 3.4 to 3.9). Away from the porphyry margins the copper grades start to decrease in the host rocks, with the rate of decrease related to the host rock and the local structures.

In the Namosi Andesite the mineralised shell has limited extent (generally less than 70m), except in several areas of intense structural deformation and porphyry dyke intrusions in the Waisoi West/Waisoi North region. Elsewhere, the Namosi Andesite (dominated by disseminated/pervasive chalcopyrite mineralisation) has low grade to sub-economic mineralisation, changing to pyrite dominated sulphides beyond approximately 70m of the porphyry margins.

Compared to the Namosi Andesite, the mineralisation in the Wainimala Agglomerate and the Basal Namosi Conglomerate (particularly near the contact between these units), generally extends further from the porphyry margins. However, mineralisation still rarely extends beyond 120m from the porphyries,

except in structural zones. Both the Wainimala Agglomerate and the Basal Namosi Conglomerate are dominated by vein mineralisation and therefore show greater local variability in the intensity (grade) of copper mineralisation depending on the intensity of local deformation.

Further work is required on the detailed distribution of the geochemical values for Cu, in particular, but also Au and Mo, and other elements such as Ag, As, Sb and other trace elements.

5.2.4 Selected Element Geochemistry

As well as the Cu, Au and Mo assays on 3m intervals, most of the drill core (in 15m composite samples) was assayed for a suite of elements by neutron activation. This suite of elements included As, Sb, Se, Sc, Ag, Ba, Ce, Cr, Co, Eu, Hf, La, Lu, Au, Mo, K, Rb, Sm, Na, Ta, Th, Te, W, Fe, U, Yb and Zn.

Several of these elements (U, W, Te) failed to be detectable in the Waisoi samples, with the only strong correlation being between Au and Cu (Figure 5.15).

A great deal of further work is required on the 3D distribution of these elements, especially in terms of mineralisation, alteration and porphyry distributions.

5.2.5 Geochemical Summary

There is abundant geochemical data available for the Waisoi porphyry deposits, but most of this data requires further evaluation.

Drainage geochemistry is the most efficient technique to locate this type of copper deposit, and then to define drilling targets. Soil geochemistry tends to be erratic due to the influence of landslip cover. Wholerock geochemistry is useful in determining the original compositions of the, commonly highly altered, host volcanics. The usefulness of trace element distributions on defining the deposits, or high-grade zones within the deposits, is unknown, but should be investigated.

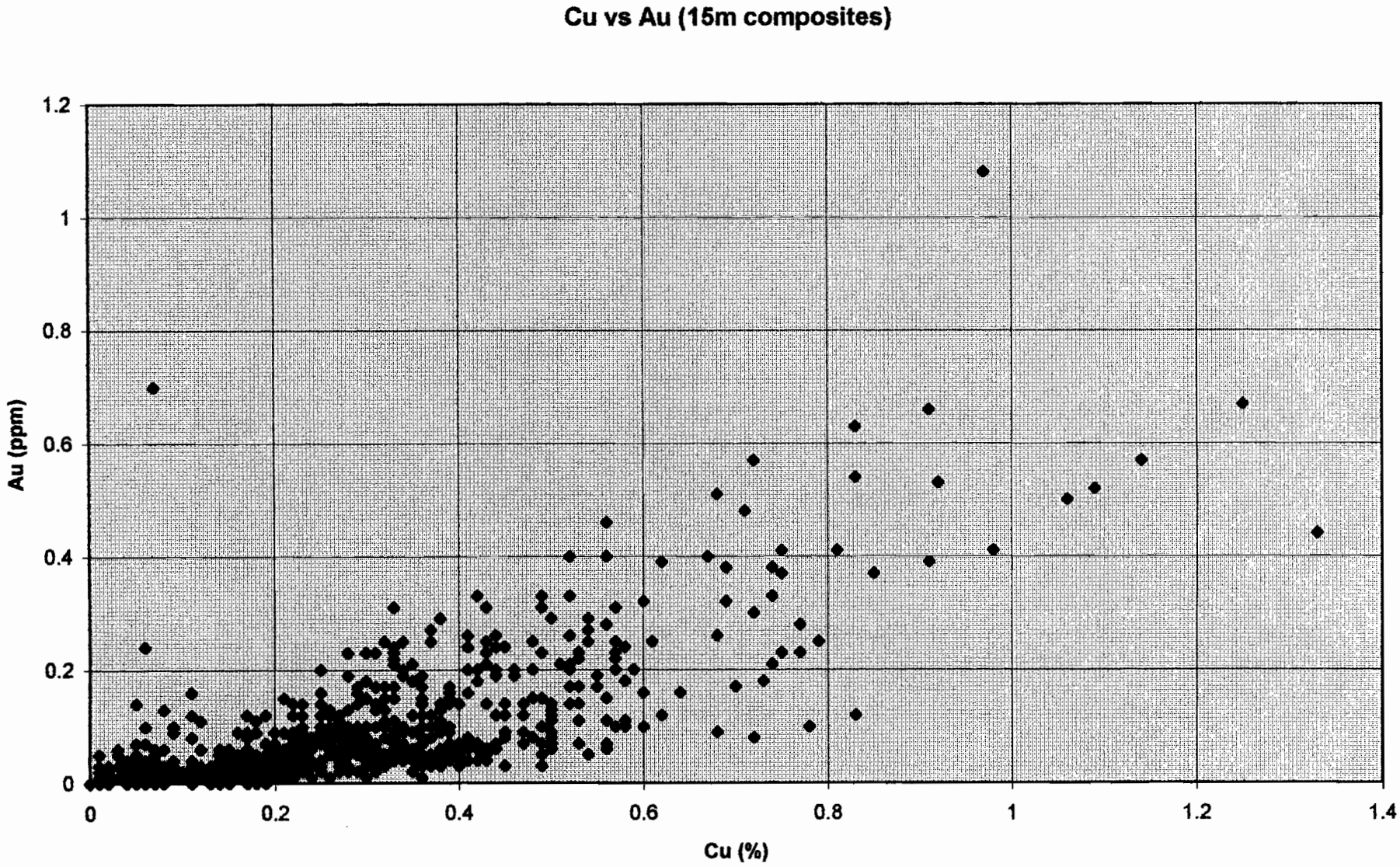


Figure 5.15 Scatter plot of copper and gold for Waisoi drilling (15m composite samples).

PART 6

GENETIC MODEL and CONCLUSIONS

6.1 GENETIC MODEL

Porphyry Cu-Au deposits are significant contributors to the world output of copper and precious metal (Singer, 1995). As such, porphyry copper deposits (preferably with gold credits) are popular exploration targets. However, there are a wide variety of porphyry-type deposits (Evstrakhin, et.al., 1986; McMillan, 1985; Candela & Holland, 1986) which make exploration difficult.

This study has highlighted several factors which may be useful in future exploration for porphyry copper mineralisation in the Fijian (or similar) environment, and in the search for higher grade zones within known deposits. These range from regional scale features (tectonic setting and structure) to local features (structures and magnetics), and other factors of unknown and/or untested use (selected element geochemistry).

On a regional scale, the complex tectonic setting of Fiji, in an area of small plates adjacent to a major subduction zone, has resulted in significant island arc volcanism followed by deformation and faulting, which led to the formation then exposure of the mineralisation. Similar situations existing in Papua New Guinea and the Philippines has led to the formation of similar types of porphyry mineralisation at Ok Tedi, Panguna, Sipalai, Atlas and Marcopper (Sillitoe, 1983; Sillitoe, 1989; Solomon, 1990). Each of these areas have also experienced a reversal in the polarity of the adjacent subduction. This reversal may have occurred later as a result of the tectonic setting of the areas in which porphyry copper mineralisation forms, rather than a reversal being necessary for porphyry formation.

The tectonic activity of the area is also responsible for the major crustal sutures which control the location of volcanism and porphyry intrusions. Such sutures appear as diffuse zones of disruption in both older and more recent rock units. These structural corridors can be located by SLAR (as was done at Waisoi) and other remote sensing techniques, including satellite and airborne surveys (Abrams et.al., 1983). Irregularities in, and intersections of, the structural corridors provide possible loci of volcanism and porphyry mineralisation. Such areas require further detailed exploration.

At Waisoi the porphyry-style mineralisation and alteration is related to the intrusion of dacitic quartz diorites along the intersection of a series of structural corridors in the basement Wainimala Agglomerate (early arc thoeliites). Prior to the commencement of the calc-alkaline (mature arc) volcanism, with which the porphyry intrusions were related, the basement Wainimala rocks had undergone regional burial metamorphism to greenschist-facies. The intrusion of the porphyries led to alteration of the metamorphosed basement rocks, and altered the overlying, phases of the calc-alkaline volcanics.

The earliest quartz diorite porphyry intrusions in the Namosi area are the northeast-southwest- trending porphyry dykes in the Waisoi West/Waisoi North area. These thin subvertical P5 dykes have been intruded along a structure associated with the Wainabama mineralisation. Mineralisation introduced during the intrusion of the P5 dykes was remobilised by a later northwest-southeast-trending compressional event. This event formed the northwest-trending quartz vein stockwork zones at Waisoi West and the Wainabama knob/ridge. The Waisoi West stockwork is less mineralised than at Wainabama due to weaker initial mineralisation associated with the P5 dykes.

After the compressional event sealed the Waisoi West stockwork, a period of relaxation allowed the injection of the main porphyry intrusions. During this event the P4 porphyry in Waisoi East and the P1 porphyries around Waisoi West and Waisoi North (better defined in 1992 by drilling and IP) were emplaced. In the north and north west of Waisoi West, several other similar porphyries inferred from the interpretation of an IP survey, appear to be confirmed by increased Cu/Au assays in nearby drilling. These P4 and P1 type intrusions are large, massive bodies which tend to have barren siliceous cores.

Mineralising fluids associated with the P1 intrusions appear to have been concentrated in the previously emplaced and structurally prepared, brecciated P5 dykes in the Waisoi North (and Waisoi West?) area. This has led to higher grades of Cu/Au mineralisation in these zones as mineralising fluids, originating from deeper P1-type intrusives, moved into areas of well-prepared (shattered) Wainimala Agglomerate and permeable Basal Namosi Conglomerate. In areas of abundant hydrothermal fracturing and structural preparation in the Waisoi

North area, the Namosi Andesite also has significant amounts of copper/gold mineralisation. Elsewhere (where there is little structural preparation) the Namosi Andesite tends to contain only low-grade or background, sub-economic levels of copper/gold.

This relates to the compositional similarities between the Namosi Andesite and the intruding mineralising porphyries (suggesting these rocks are co-magmatic). The chemical similarity between the Namosi Andesite and the porphyries makes the Namosi Andesite chemically unfavourable for the deposition of significant minerals from fluids originating in the porphyries. The lack of a significant change in the chemistry between the intrusives and the lavas results in the Namosi Andesite mineralisation tending to be weak and disseminated. Zones of pervasive silicification in areas where the porphyries intrude the lavas and volcaniclastics of the Namosi Andesite around Waisoi West are possibly caused by reduced reaction and precipitation as fluids from the intrusives flow through the chemically similar, and co-magmatic (with the intrusives) volcanics. Precipitation of silica may have occurred due to temperature decreases.

This contrasts with the stronger mineralisation in the underlying units (Wainimala Agglomerate and Basal Namosi Conglomerate) which is permeability-controlled on fractures, joints, openings and pore-space, as well as some disseminated mineralisation. The mineral deposition in these rocks is controlled by physico-chemical changes in the fluids caused by the differing rock properties between the source of the fluids and the depositional environment. Mineralisation in the top of the porphyries is also fracture-controlled and disseminated.

Although similar, the mineralisation and alteration of the Basal Namosi Conglomerate varies from that in the Wainimala Agglomerate due to the grain size and/or composition variability of the fragments in the Basal Namosi Conglomerate, and to the ponding effect of the overlying Namosi Andesite. Within the conglomerate (and with increasing influence higher in the unit) the felsic volcanic fragments appear to be "tighter" and less mineralised and altered than adjacent more mafic, shattered, volcanic fragments. Thus in most samples

of altered Basal Namosi Conglomerate the mafic volcanic fragments are often more intensely mineralised than adjacent, more felsic fragments.

At Waisoi West the major controls on the focussing of mineralisation are intersections of northwest- and northeast-trending structural zones, which are also the main control for the location of the P1 intrusives. The intrusion of the over-pressured P1 porphyries caused shattering of the porphyry margins and the surrounding Wainimala Agglomerate wallrock. This allowed fluids from the porphyries to pass through the shattered Wainimala Agglomerate and the more permeable Basal Namosi Conglomerate resulting in the deposition of copper sulphide mineralisation in the outer portions of the porphyries and the permeable wallrocks. The Namosi Andesite tended to act as a cap to the Waisoi West system, with only limited areas where it contains significant mineralisation.

At Waisoi East the location of the porphyries is controlled by the intersections of northwest- and northeast-trending structural zones. However, unlike the Waisoi West porphyries, the near-surface portions of the Waisoi East porphyries are the more massive, lower levels of the intrusives, with some higher level apophyses towards the eastern edge of the deposit. The main zone of mineralisation is again in the edges of the porphyry intrusions and the surrounding permeable wallrocks.

The Namosi Andesite lavas and volcaniclastics appear to have acted as a cap for mineralisation (except where penetrated by porphyries) leading to a ponding of fluids in the upper part of the Wainimala Agglomerate and in the Basal Namosi Conglomerate. Mineralisation in this zone tends to migrate laterally beneath the overlying Namosi Andesite cap. In these areas the main concentration of mineralisation tends to be at the Wainimala Agglomerate/ Basal Namosi Conglomerate contact and/or the Basal Namosi Conglomerate/ Namosi Andesite contact.

The main P4 porphyry body in Waisoi East appears to be partially surrounded by similar composition P4 porphyry "ring" dykes. These dykes appear to be later than the main P4 intrusion, and are subvertical, thin bodies with only weak Cu/Au mineralised haloes.

To the south of the southern ring dykes in Waisoi East is a porphyry dyke-like body that truncates the P4 type mineralisation. This dyke is weakly mineralised but has a very low Au to Cu ratio (much lower than the P4 mineralisation) (Figures 3.3 to 3.9).

On a local scale, structure again is important in controlling the localisation of vulcanism, intrusives and mineralisation. Structures also provide a path for leakage from any mineralised systems to the atmosphere. This allows geochemistry (in particular drainage geochemistry) to be used to locate zones of potential mineralisation. At Waisoi drainage geochemistry (analysing for Cu, CxCu and Au +/- Zn, Mo and As) was the most useful geochemical technique, and when used in conjunction with geological mapping (including geology, structure and veining) was effective in locating zones of buried to sub-cropping porphyry mineralisation (such as North Waisoi).

As well as providing foci for porphyry intrusions and leakage paths for mineralisation, structures also provide a means by which mineralisation can be concentrated by later remobilisation. Apart from a small area at Waisoi North, post-mineralisation upgrading does not appear to be important. However, the major part of Waisoi North appears to have undergone a structural preparation (shattering) which has resulted in a primary upgrading of copper occurring during the mineralising event. Such upgraded zones tend to have mineralisation dominated by bornite, biotite and magnetite, the latter mineral providing the opportunity of being recognised by a detailed magnetic survey. This could be useful at Waisoi to determine if there are any significant high-grade zones, particularly in the under-drilled areas around Waisoi North.

In terms of techniques which may be useful in vectoring-in on centres of mineralisation and/or high-grade pods of mineralisation, lithogeochemistry studies using trace element and selected element analyses provide the greatest opportunities (Nurmi, 1985; Olade & Fletcher, 1976; Jones, 1992; Golovanov, et.al., 1986). Currently there is an abundance of geochemical data available for the Waisoi mineralised zone, and this requires detailed evaluation prior to the collection of any further data.

6.2 CONCLUSIONS

The Waisoi porphyry copper deposit consists of three distinct centres of mineralisation known as Waisoi East, Waisoi West and Waisoi North. Together these deposits total 930 million tonnes grading 0.43% copper and 0.14 ppm gold (using a 0.3% Cu cut-off).

These deposits are hosted in volcanics and volcaniclastics near the dis-conformable contact between the basement submarine basaltic andesites of the Wainimala Agglomerate (+10Ma) and the dominantly subaerial, calc-alkaline dacites of the Namosi Andesite (5.7 - 6.0 Ma). This contact includes the intervening Basal Namosi Conglomerate, a volcanic derived series of mass flows which mark the commencement of calc-alkaline volcanism. The mineralisation resulted from the intrusion of dacitic quartz diorite porphyries of similar composition to, and co-magmatic with, the Namosi Andesite lavas. These porphyries intruded the Wainimala Agglomerate, Basal Namosi Conglomerate and Namosi Andesite prior to the deposition of large thicknesses of volcaniclastics with mineralised inclusion, known as the Korobasabasaga Pyroclastics.

Both the early island arc volcanism of the older Wainimala Agglomerate and the mature island arc volcanism of the Namosi Andesite and Korobasabasaga Pyroclastics are related to subduction along the southwest dipping Vitiaz Trench.

The Waisoi porphyry mineralisation is controlled by structures associated with large regional sutures related to the original tectonics of Fiji, and visible across the width of Viti Levu. On a local scale the foci of mineralisation are dominantly northeast and northwest trending structures, the intersection of which form a loci of porphyry intrusions (Figure 3.13). Alteration and mineralisation are broadly zoned away from the porphyry intrusions, such that the sequence is:

barren, silica core to the porphyries,

high-grade bornite, biotite +/- magnetite with sericite +/- clay, K-feldspar zone in the outer porphyries and surrounding host rock (dominantly fracture controlled vein mineralisation),

moderate-grade chalcopyrite, chlorite, silica zone (a mix of disseminated and fracture controlled vein mineralisation),

low-grade pyrite, chalcopyrite, chlorite, silica, (dominantly disseminated mineralisation),

an outer propyllitically altered zone with chlorite, pyrite, carbonate, silica and epidote

The relative timing of the mineralisation and alteration, determined from the polished thin section petrological and mineralogical study, shows:

	Stage	Sub-stage	Minerals
Pre Porphyry	regional	albitisation	albite,quartz
		metamorphism	albite-biotite-chlorite-actinolite
Porphyry	sericitisation		sericite-quartz+/-pyrite
	silicification		quartz-chlorite+/-pyrite-chalcopyrite
	mineralisation potassic	main	quartz-biotite-magnetite-bornite-chalcopyrite+/-K-feldspar
	chloritisation	late	quartz-chlorite-sericite-chalcopyrite+/-pyrite
	carbonate	early	calcite-quartz+/-chlorite-pyrite-chalcopyrite
		late	calcite+/-quartz-chlorite-pyrite-epidote-analcime

Copper was deposited during most of the porphyry phases of mineralisation and alteration, but the majority of the copper was deposited during the introduction of potassic alteration. During this stage most of the copper was deposited as bornite and chalcopyrite, with dominantly chalcopyrite in the early and late stages of the porphyry mineralisation. Gold is directly associated with copper mineralisation in both the bornite and chalcopyrite phases of mineralisation.

These events resulted from the introduction of a series of fluids including:

a high temperature fluid (>480^{0}C) with high and variable salinities

a high salinity, high temperature fluid (>380^{0}C, +45 wt.% NaCl equivalent)

a lower salinity, lower temperature fluid (<300^{0}C, 10 wt.% NaCl equivalent)

Other fluids were also present, including a late stage, low temperature fluid (around 250^{0}C) of uncertain affinities. The relative timing of some of these various fluids is uncertain due to many of the fluid inclusions being secondary and thus occurring in more than one phase of the mineralisation. It is likely that the fluids responsible for the early phases of mineralisation were dominantly magmatic with high temperatures and salinities. The later, lower temperature phases of mineralisation and alteration were probably due to the mixing of meteoric fluids as the magmatic circulation decreased and waned.

Higher-grade copper and gold mineralisation occurs only adjacent to the porphyry margins and in the adjacent brecciated host rocks. This is in the vicinity of the Waisoi West and Waisoi North porphyries where bornite is the dominant sulphide species. These are areas of higher temperature phases, probably where higher fluid flows have occurred in structurally, well-prepared zones. As the bornite is associated with magnetite (and biotite), the higher-grade zones may be located and their possible extent defined by detailed magnetic surveys (possibly low-level heli-magnetic surveys).

This study has defined the geology, mineralisation and alteration of the Waisoi porphyry copper/gold deposits, determined a mineral paragenesis and composition of the mineralising fluids and suggested a genetic model and interpretation for the development of the deposits. It has also suggested several area for further evaluation and several techniques for further exploration.